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Zenon Environmental Inc.

ZenoGem® Biological and Ultrafiltration Technology

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

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Foreword

The U. S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director

National Risk Management Research Laboratory

Abstract

Zenon Environmental Inc. (Zenon), of Burlington, Ontario, Canada has developed an innovative wastewater treatment technology called the ZenoGem® technology. The ZenoGem® technology integrates biological treatment with membrane-based ultrafiltration to treat wastewater with high concentrations of organic contaminants that cause elevated concentrations of chemical oxygen demand (COD). The system reduces organic contaminants in wastewater to below regulatory limits, improves effluent quality, reduces sludge production, resists contaminant shock-loading, and, by maintaining a long sludge retention time, reduces the size of the bioreactor necessary for performing bioremediation.

The Superfund Innovative Technology Evaluation (SITE) demonstration occurred between September and December 1994 at the Nascolite Superfund site (Nascolite) in Millville, Cumberland County, New Jersey. In 1985, a remedial investigation and feasibility study at the Nascolite site revealed that groundwater was contaminated with methyl methacrylate (MMA), volatile organic compounds (VOC), and heavy metals.

The basic components of the ZenoGem® system are an influent-holding equalization tank, a bioreactor, an air blower, a pH buffer tank, a nutrient solution tank, an ultrafiltration module, optional off-gas carbon filters, optional permeate carbon filters, and feed, process, and metering pumps. The system components are computer-controlled and equipped with alarm indicators to notify the operator of mechanical and operational problems.

During the SITE demonstration, critical and noncritical measurements were evaluated. Critical measurements consisted of sample analyses and process measurements that directly impacted meeting the project's primary technical objective. Critical measurements included collection of liquid and air samples for MMA and VOC analyses; liquid samples to evaluate COD; and flow rate measurements of the influent and effluent liquid streams. Noncritical, or system condition measurements, provided information on operating ranges, reliability, variability, cost-effectiveness, and full-scale remediation potential of the technology.

The results of the sample analyses indicated that the technology consistently surpassed the demonstration goal of 95 percent reduction for MMA (99.99 $\pm$ 0.01 percent) and COD (96.8 $\pm$ 5.0 percent). The high removal efficiency for MMA and reduction of COD was maintained after a 3-fold concentration was delivered to the system (shock-loading test), suggesting that a sudden increase in influent MMA and COD concentration had little noticeable effect on the technology's performance. Reductions of greater than 97 percent were noted in all VOCs reported (methylene chloride, trichloroethene, benzene, toluene, and o+p xylenes). Based on extrapolation from the air sample concentration data and the flow meter readings, the total volatilization of MMA and VOCs from the system calculated less than 0.10 percent of the total MMA and VOC mass treated during the demonstration. No major operating problems occurred during the SITE demonstration period; no significant changes in technology performance were observed during the SITE demonstration.

EPA SITE Program personnel prepared this Innovative Technology Evaluation Report (ITER) to present the results of the SITE Program demonstration. The ITER evaluates the ability of the ZenoGem® technology to treat contaminated groundwater based on the demonstration results. Specifically, this report discusses performance and economic data collected by SITE Program personnel, and also presents case studies and additional information about the technology provided by Zenon.

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Acronyms, Abbreviations, and Symbols

AEA	Atomic Energy Act
ACL	Alternate concentration limits
ARAR	Applicable or relevant and appropriate requirement
BACT	Best available control technology
bgs	Below ground surface
BOD	Biological oxygen demand
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COD	Chemical oxygen demand
CWA	Clean Water Act
DO	Dissolved oxygen
DOE	Department of Energy
GC	Gas chromatography
EPA	U.S. Environmental Protection Agency
gpd	Gallons per day
gpm	Gallons per minute
ITER	Innovative Technology Evaluation Report
kWh	Kilowatt-hour
MCL	Maximum Concentration Limit
µg/L	Micrograms per liter
mg/L	Milligrams per liter
MMA	Methyl Methacrylate
MS/MSD	Matrix spike/matrix spike duplicate
NAPL	Nonaqueous-phase liquid
NAAQS	National Ambient Air Quality Standards
NJDEP	New Jersey Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NH_3	Ammonia
NO_3^-/NO_2^-	Nitrate/nitrite
NRC	Nuclear Regulatory Commission
O&M	Operation and Maintenance
ORD	EPA Office of Research and Development

Acronyms, Abbreviations, and Symbols (continued)

ORP	Oxidation reduction potential
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
POTW	Publicly owned treatment works
PO_4^{-3}	Phosphate
PPE	Personal protective equipment
PSD	Prevention of significant deterioration
psi	Pound per square inch
QAPP	Quality assurance project plan
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial investigation/feasibility study
RO	Reverse Osmosis
SDWA	Safe Drinking Water Act
SARA	Superfund Amendments and Reauthorization Act
scf	Standard cubic feet
scfm	Standard cubic feet per minute
SITE	Superfund Innovative Technology Evaluation
sg	Specific gravity
STP	Standard temperature and pressure
TCL	Target compound list
TER	Technical Evaluation Report
TOC	Total organic carbon
TSD	Treatment storage and disposal
TSS	Total suspended solids
µg/L	Micrograms per liter
UF	Ultrafiltration
VOC	Volatile organic compound
VSS	Volatile suspended solids
Zenon	Zenon Environmental Systems Inc.

Conversion Factors

	To Convert From	To	Multiply By
Length	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(°Fahrenheit - 32)	°Celsius	0.556

Acknowledgments

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Special acknowledgment is given to Mr. F. Anthony Tonelli and Mr. Ake Deutschmann of Zenon Environmental Inc., Burlington, Ontario, Canada; Mr. Mike Merdinger of Foster Wheeler Environmental Corporation (previous SITE Program contractor for the ZenoGem® demonstration); the site owner; and the New Jersey Department of Environmental Protection for their cooperation and support during the SITE demonstration and during the development of this report.

Executive Summary

Zenon Environmental Inc. (Zenon), of Burlington, Ontario, Canada has developed an innovative wastewater treatment technology called the ZenoGem® technology. This technology is designed to treat groundwater, landfill leachate, industrial effluent, or soil-washing effluent contaminated with high concentrations of organic compounds. The ZenoGem® technology uses aerobic biological treatment to remove biodegradable organic compounds from the target influent and ultrafiltration to separate residual suspended solids from the treated effluent.

The purpose of this Innovative Technology Evaluation Report (ITER) is to present information that will assist Superfund decision-makers in evaluating this technology's suitability for remediating a particular hazardous waste site. The report provides an introduction to the Superfund Innovative Technology Evaluation (SITE) Program and the ZenoGem® technology and discusses the demonstration objectives and activities, evaluates the technology's effectiveness, analyzes key factors pertaining to application of this technology, analyzes the cost of using the technology to treat contaminated groundwater and leachate, and summarizes the technology's current status.

This executive summary briefly summarizes the information discussed in the ITER and evaluates the technology with respect to the nine criteria used in Superfund feasibility studies.

Technology Description

The ZenoGem® technology integrates biological treatment with membrane-based ultrafiltration to treat wastewater with high concentrations of organics contaminants that cause elevated concentrations of chemical oxygen demand (COD). Zenon claims that the process reduces organic contaminants in wastewater to below regulatory limits, improves effluent quality, reduces sludge production, resists contaminant shock-loading, and, by maintaining a long sludge retention time, reduces the size of the biological reactor (bioreactor) necessary for performing bioremediation.

This system uses ex-situ bioremediation to treat contaminated groundwater in an enclosed suspended growth bioreactor. According to Zenon, the ZenoGem® process derives an advantage over conventional wastewater treatment processes due to its membrane-based ultrafiltration technology. The ultrafilter not only filters the treated water (permeate) prior to discharge and recycles the biological solids (concentrate), but also recovers the higher-molecular-weight soluble materials that would otherwise pass through conventional clarifiers and filters. These higher-molecular-weight materials are returned to the bioreactor for further biodegradation prior to ultimate discharge. The combination of biological treatment with ultrafiltration proves to be an effective means of not only degrading organic compounds, but also in minimizing the amount of waste solids typically associated with biological treatment operations.

Overview of the ZenoGem® Technology SITE Demonstration

The SITE demonstration of the ZenoGem® technology occurred between September and December 1994 at the Nascolite Superfund site (Nascolite) in Millville, Cumberland County, New Jersey. Nascolite manufactured acrylic plastic sheets at the site from 1953 to 1980. The company used methyl methacrylate (MMA) monomer as a raw material and operated a MMA reclamation process. Solid acrylic, liquids, and resins containing MMA were purchased from outside sources. This material was processed through depolymerization, using a molten lead bath followed by distillation and purification. Waste residue from the distillation processes was stored in several underground storage tanks in the northern plant area. In 1985, a remedial investigation and feasibility study at the Nascolite site revealed that groundwater was contaminated with MMA, various other EPA target compound list (TCL) volatile organic compounds (VOC), and heavy metals.

For the SITE Program demonstration, a pilot-scale ZenoGem® system was used to treat groundwater at the Nascolite site. For the SITE demonstration, the pilot-scale system was housed in a transportable trailer, which required a 12-foot by 60-foot area to support the system and its components' maximum operating weight of 45,000 pounds. Zenon indicated that these measurements are specific to the trailer used for the SITE demonstration, and that Zenon's projects usually do not include a trailer-mounted system.

The basic components of the ZenoGem® system used in the demonstration include: an influent-holding equalization tank, a bioreactor, an air blower, a pH buffer tank, a nutrient solution tank, an ultrafiltration module, optional off-gas carbon filters, optional permeate carbon filters, and feed, process, and metering pumps. According to Zenon, off-gas and permeate carbon filters are not standard components of the ZenoGem® system; however, carbon filters may be used depending on site-specific conditions. The system components are computer-controlled and equipped with alarm indicators to notify the operator of mechanical and operational problems. The entire pilot-scale system, except for the main air blower and optional carbon filters, is mounted inside the 8-foot by 48-foot trailer. The trailer also is equipped with a laboratory that enables field personnel to evaluate system performance.

The primary objective of the SITE demonstration was as follows:

- Determine if the ZenoGem® treatment system (integrating the bioreactor and ultrafiltration unit as a whole) can achieve a 95 percent or greater removal efficiency for MMA and TCL VOCs and reduce COD at a 95 percent confidence level

The secondary objectives of the demonstration were as follows:

- Evaluate system performance by measuring system parameters that will provide data on operating ranges, reliability, variability, cost-effectiveness, and full-scale remediation potential
- Estimate approximate capital and operations and maintenance (O&M) costs for the demonstration and for full-scale remediation

During the SITE demonstration, critical and noncritical measurements were evaluated. Critical measurements consisted of sample analyses and process measurements that directly impacted meeting the project's primary technical objective. Critical measurements included collection of liquid and air samples for MMA and TCL VOC analyses; liquid samples to evaluate COD; and flow rate measurements of the influent and effluent liquid streams. Flow rate measurements were used during calculations of the ZenoGem® system's total reduction of MMA, TCL VOCs, and COD concentrations between the influent and effluent streams.

Noncritical, or system condition measurements, provided information on operating ranges, reliability, variability, cost-effectiveness, and full-scale remediation potential of the technology. System measurements included sample collection and laboratory analyses for the following: total suspended solids, volatile suspended solids, total metals, total organic carbon, nutrients (ammonia, nitrate/nitrite, and phosphate), oxygen, and carbon dioxide. System measurements also included measurements for pH, dissolved oxygen, temperature, oxidation reduction potential, and specific gravity.

Samples indicated that influent groundwater during the demonstration contained MMA concentrations ranging from 567 to 9,500 milligrams per liter (mg/L); methylene chloride concentrations ranging from 500 to 15,300 micrograms per liter (μg/L); trichloroethene concentrations ranging from 852 to 905 μg/L; benzene concentrations ranging from 279 to 282 μg/L (these were the only two detections of the contaminant in the influent during the demonstration); and COD concentrations ranging from 1,490 to 19,600 mg/L. Toluene and the o- and p- forms of xylenes were detected only once during the demonstration at concentrations of 105 μg/L and 14,400 μg/L, respectively.

Based on SITE Program data and postdemonstration data obtained by Zenon, the average flow rates for the pilot-scale unit ranged between 380 to 620 gallons per day (gpd). Based on the daily flow rates, the system treated about 47,200 gallons of contaminated groundwater during the demonstration.

SITE Demonstration Results

The following items summarize the significant results of the SITE demonstration:

- The permeate MMA removal efficiencies consistently surpassed the demonstration goal of 95 percent reduction. The average removal efficiency for MMA was greater than 99.98 $\pm$ 0.01 percent for the 3 month demonstration. MMA analyses from the treated effluent stream following the optional permeate carbon filters improved the average removal efficiency of the system to 99.99 $\pm$ 0.01 percent. The high removal efficiency for MMA was maintained after a 3-fold concentration was delivered to the system (shock loading test), suggesting that a sudden increase in influent MMA concentration had little noticeable effect on the technology's performance.

- The permeate COD reduction efficiencies varied from 84.7 percent to 95.6 percent, yielding an overall COD reduction efficiency of 88.6 $\pm$ 8.4 percent. COD analyses from the treated effluent stream following the optional permeate carbon filters improved the average reduction efficiency of the system to 96.8 $\pm$ 5.0 percent. The high reduction efficiency for COD was maintained after the shock loading test, suggesting that a sudden increase in influent COD concentration had little noticeable effect on the technology's performance.

- Due to high MMA concentrations in the influent, the laboratory was unable to analyze aqueous TCL VOC samples at a low enough dilution factor to quantify the low concentrations of TCL VOCs. Therefore, detection limits were low enough in only five of 71 samples collected to quantify TCL VOC concentrations. Consequently, removal efficiencies for individual TCL VOCs could not be calculated for the majority of the samples collected during the demonstration. Reductions of greater than 97 percent were noted in all TCL VOCs reported (methylene chloride, trichloroethene, benzene, toluene, and o- and p- xylenes).

- Based on extrapolation from the air sample concentration data and the flow meter readings, the total volatilization of MMA and TCL VOCs from the system calculated was computed to be about 411 grams. This value represent less than 0.10 percent of the total MMA and TCL VOC mass treated during the demonstration.

- No major operating problems occurred during the SITE demonstration period; no significant changes in technology performance were observed during the SITE demonstration.

Cost Analysis

Using information obtained from the SITE demonstration, Zenon, and other sources, a cost analysis examined 12 cost categories for two different hypothetical applications of the ZenoGem® technology. Case 1 assumes that a rented, trailer-mounted system treats groundwater at a rate of 1,400 gpd for a 1-year period. Case 2 assumes that a modular (skid-mounted) system will be purchased and used to treat leachate at a rate 1,400 gpd for a 10-year period. The cost estimate assumed that the site hydrogeology and the general types and concentrations of TCL VOCs were the same as those encountered during the Nascolite demonstration. Based on these assumptions, the total costs for Case 1 were estimated to be about $0.50 per gallon of groundwater treated and for Case 2 were estimated to be $0.22 per gallon of leachate treated. The estimated Case 1 cost per gallon is approximately 55 percent higher than the cost per gallon in Case 2, primarily due to the assumed short length of the remediation period in Case 1, which limits the volume potentially treated. Costs for actual applications of the ZenoGem® technology may vary significantly from these estimates, depending on site-specific factors.

Superfund Feasibility Study Evaluation Criteria for the ZenoGem® Technology

Table ES-1 briefly discusses an evaluation of the ZenoGem® technology with respect to the nine evaluation criteria used for Superfund feasibility studies when considering remedial alternatives at Superfund sites.

Table ES-1. Superfund Feasibility Study Evaluation Criteria for the ZenoGem® Technology

Criterion	Discussion
Overall Protection of Human Health and the Environment	• The technology is expected to protect human health and the environment by degrading organic contaminants in groundwater to innocuous materials such as carbon dioxide, methane, water, inorganic salts, microbial biomass, and other by-products that are less hazardous than parent materials.
Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	• The technology's ability to comply with existing federal, state, or local ARARs should be determined on a site-specific basis. • The treated effluent was accepted for discharge by the local publicly owned treatment works during the Nascolite demonstration.
Long-Term Effectiveness and Permanence	• Human health risk can be reduced to acceptable levels by treating groundwater to site-specific cleanup levels; the time needed to achieve cleanup goals depends primarily on contaminant characteristics and system flow rates. • The results of a shock-loading test indicated that the technology resisted upsets due to instantaneous increases in MMA and COD concentrations in the influent stream. MMA and COD removal efficiencies remained greater than 95 percent in the treated effluent.
Reduction of Toxicity, Mobility, or Volume Through Treatment	• The mixed liquor is retained in the bioreactor for sufficient time to allow the microorganisms to degrade the biodegradable organic contaminants into innocuous materials such as carbon dioxide, water, inorganic salts, microbial biomass, and other by-products that are less hazardous than parent materials. • Zenon can reduce the volume of waste sludge for disposal by continuously recirculating the contents through the ultrafiltration module. This procedure dewaters and concentrates the sludge, yielding a smaller volume for disposal.
Short-Term Effectiveness	• The results of the demonstration indicate that the technology degrades MMA, TCL VOCs, and reduces COD.

Table ES-1. Superfund Feasibility Study Evaluation Criteria for the ZenoGem® Technology (continued)

Criterion	Discussion
Implementability	• The actual amount of space required for the ZenoGem® system depends on the size of the system used. For the Nascolite demonstration, the pilot-scale system was housed in a transportable trailer. The trailer requires a 12-foot by 60-foot area to support a maximum operating weight of 45,000 pounds. • The site must be accessible to typical construction equipment and delivery vehicles. • Additional space (beyond the 720 square feet required for the treatment technology) is required for optional untreated and treated groundwater storage tanks, and a drum staging area for generated wastes. Additionally, a building or shed is useful to protect supplies. Other installation and monitoring requirements include security fencing and access roads for equipment transport. • The ZenoGem® technology is not designed to operate at temperatures near or below freezing. If such temperatures are anticipated, the technology and associated storage tanks should be installed in a climate-controlled environment. In addition, aboveground piping to the technology must be protected from freezing. • The ZenoGem® technology requires 460-volt, 3-phase, 60-hertz, 30-ampere electrical service.
Cost	• A rented system operating for a 1-year period results in total fixed and variable costs of about $263,800. This total results in a cost of $0.50 per gallon treated. A purchased system operating for a 10-year period results in total fixed and variable costs of about $1,200,000. This total results in a cost of $0.22 per gallon treated.
Community Acceptance	• This criterion is generally addressed in the record of decision after community responses are received during the public comment period. However, because communities are not expected to be exposed to harmful levels of VOCs, noise, or fugitive emissions, community acceptance of the technology is expected to be relatively high.
State Acceptance	• This criterion is generally addressed in the record of decision; state acceptance of the technology will likely depend on the long-term effectiveness of the technology.

Section 1
Introduction

This section describes the Superfund Innovative Technology Evaluation (SITE) Program and the Innovative Technology Evaluation Report (ITER); provides background information on bioremediation and the Zenon Environmental Systems Inc. (Zenon), ZenoGem® biological and ultrafiltration technology; provides an overview and objectives of the SITE demonstration; and provides a list of key contacts.

1.1 Description of SITE Program and Reports

This section provides information about (1) the purpose, history, and goals of the SITE Program; and (2) the reports used to document SITE demonstration results.

1.1.1 Purpose, History, and Goals of the SITE Program

The primary purpose of the SITE Program is to advance the development and demonstration, and thereby establish the commercial availability, of innovative treatment and monitoring technologies applicable to Superfund and other hazardous waste sites. The SITE Program was established by the U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), which recognized the need for an alternative or innovative treatment technology research and demonstration program. The SITE Program is administered by ORD's National Risk Management Research Laboratory. The overall goal of the SITE Program is to carry out a program of research, evaluation, testing, development, and demonstration of alternative or innovative treatment technologies that may be used in response actions to achieve more permanent protection of human health and welfare and the environment.

The SITE Program consists of the following four programs: (1) the Emerging Technology Program, (2) the Demonstration Program, (3) the Characterization and Monitoring Program, and (4) the Technology Transfer Program. This ITER was prepared under the SITE Demonstration Program.

The objective of the SITE Demonstration Program is to provide reliable performance and cost data on innovative technologies so that potential users can assess a given technology's suitability for specific cleanups. To produce useful and reliable data, demonstrations are conducted at hazardous waste sites or under conditions that closely simulate actual waste site conditions.

Information collected during the demonstration is used to assess the performance of the technology, the potential need for pre- and posttreatment processing of the waste, the types of wastes and media that may be treated by the technology, potential operating problems, and the approximate capital and operating costs. Demonstration information also can provide insight into a technology's long-term operating and maintenance (O&M) costs and long-term application risks.

Each SITE demonstration evaluates a technology's performance in treating waste at a particular site. Successful demonstrations of a technology at one site or on a particular waste does not ensure its success at other sites of for other wastes. Data obtained from the demonstration may require extrapolation to estimate a range of operating conditions over which the technology performs satisfactorily. Extrapolation of demonstration data should be based on other information about the technology, such as information available from case studies.

Implementation of the SITE Program is a significant, ongoing effort involving ORD, OSWER, various EPA regions, and private business concerns, including technology developers and parties responsible for site remediation. The technology selection process and the Demonstration Program together provide objective and carefully controlled testing of field-ready technologies. Innovative technologies chosen for a SITE demonstration must be pilot- or full-scale applications and must offer some advantage over existing technologies; mobile technologies are of particular interest.

1.1.2 Documentation of SITE Demonstration Results

The results of each SITE demonstration are reported in an ITER and a Technology Evaluation Report (TER). Information presented in the ITER is intended to assist Superfund decision-makers evaluating specific technologies for a particular cleanup situation. The ITER represents a critical step in the development and commercialization of a treatment technology. The ITER report discusses the effectiveness and applicability of the technology and analyzes costs associated with its application. The technology's effectiveness is evaluated based on data collected during the SITE demonstration and from other case studies. The applicability of the technology is discussed in terms of waste and site characteristics which could affect technology performance, material handling requirements, technology performance, and other factors for any application of the technology.

The purpose of the TER is to consolidate all information and records acquired during the demonstration. It contains both a narrative portion and tables and graphs summarizing the data. The narrative portion includes discussions of demonstration activities, as well as deviations from the demonstration quality assurance project plan (QAPP). The data tables and graphs summarize demonstration results relative to project objectives. The tables also summarize quality assurance and quality control (QA/QC) data and data quality objectives. The TER is not formally published by EPA; instead, a copy is retained as a reference by the EPA project manager for responding to public inquiries and for recordkeeping purposes.

1.2 Description of Bioremediation

Bioremediation is the process by which hazardous organic materials are degraded by microorganisms (typically, heterotropic bacteria and fungi) to innocuous materials such as carbon dioxide, water, inorganic salts, microbial biomass, and other by-products that are usually less hazardous than parent materials. Biological treatment has been a major component for many years in the treatment of municipal and industrial wastewaters. In recent years, bioremediation concepts have been applied in treating hazardous wastes and remediating contaminated groundwater and soils. For example, bioremediation has been used for degrading creosote in wastes from wood treatment, as well as petroleum hydrocarbons in refinery wastes, oil spills, and subsurface material contaminated by fuels from leaking underground storage tanks.

The two processes associated with bioremediation are natural and enhanced bioremediation. Natural bioremediation technologies, sometimes referred to as intrinsic bioremediation, depend on indigenous microflora to degrade contaminants using only nutrients and other factors that are available in situ. Enhanced bioremediation technologies, such as the ZenoGem® technology, increases biodegradation rates by supplying nutrients, oxygen, and other factors that are rate limiting. Examples of in situ processes include, bioventing, air sparging, and in-situ biological. Ex situ processes include slurry reactors and prepared beds for soil and sludges, pile/composting for soil, and fluidized reactors and wastewater treatment plants for aqueous wastes.

Generally, the capital and operating costs for actual applications of bioremediation technologies vary depending on the types and quantity of organic compounds present, site conditions, the volume of material to be processed, and site-specific remediation goals. However, the main direct costs associated with bioremediation can be attributed to transferring the contaminated wastewater to the treatment unit (typically a biological reactor [bioreactor] or reaction zone) and supplying oxygen and nutrients to aerobic treatment systems. The estimated costs associated with the ZenoGem® technology are presented in Section 4.0. The ZenoGem® technology is discussed in the following section.

1.3 The ZenoGem® Technology

The ZenoGem® technology integrates aerobic biological treatment with membrane-based ultrafiltration. This innovative system uses ex situ bioremediation to treat contaminated groundwater in an enclosed, suspended growth bioreactor. The system uses the ZENON PermaFlow® ultrafiltration cross-flow membrane and system to seperate virtually all solids from the treated effluent. The membrane and system are characterized by a wide-diameter, series flow, tubular construction. The combination of biological treatment with ultrafiltration proves to be an effective means of not only degrading organic compounds but minimizing the amount of waste solids that are typically associated with biological treatment. According to Zenon, about 0.1 pound of sludge is generated per pound of COD removed from the influent stream. A simplified schematic diagram of the ZenoGem® system is shown in Figure 1-1.

Zenon claims that the ZenoGem® technology derives an advantage over conventional wastewater treatment processes due to its membrane-based ultrafiltration technology. The ultrafilter not only filters the treated water prior to discharge and recycles the biological solids, but also recovers the higher-molecular-weight, soluble materials that would otherwise pass through conventional clarifiers and filters. These higher-molecular weight materials are returned to a bioreactor for further biodegradation prior to ultimate discharge. Integrated biological contactor/membrane separator technology has developed rapidly in recent years as improved membrane chemistries and configurations produced modules with higher fluxes and lower potential fouling.

Ultrafiltration is a pressure-driven, cross-flow filtration process in which the wastewater to be processed flows tangentially over the surface of a membrane filter capable of separating both insoluble materials (bacteria, colloids, suspended solids) and higher-molecular-weight soluble materials from the treated water. The threshold size above which organic compounds are retained by the membrane and below which they pass through the membrane is called the molecular size cut-off. Zenon claims that the molecular size cut-off for the ZenoGem® technology ranges from 0.003 microns (μ) to 0.1 μ and depends on the specific membrane chemistry. The typical operating pressure of an ultrafiltration system is 60 to 70 pounds per square inch (psi). According to Zenon, the UF membranes require replacement every 3 years and cleaning is required when the effluent flow rate is reduced about 20 percent when compared to the design flow rate of the system. Additional information on replacement cost is provided in Section 4.0 - Economic Analysis.

The basic components of the ZenoGem® technology are an influent holding-equalization tank, a bioreactor, an air blower, a pH buffer tank, a nutrient solution tank, an ultrafiltration module, optional off-gas carbon filters, optional permeate carbon filters, and feed, process, and metering pumps. The technology components are computer-controlled and equipped with audible alarm indicators to notify the operator of mechanical and operational problems. The entire pilot-scale system, except for the main air blower and optional activated-carbon filters, is mounted inside an 8-foot by 48-foot trailer. The trailer also is equipped with a laboratory that enables field personnel to evaluate technology performance.

Treatment begins by pumping wastewater into a 1,000-gallon, polyethylene, stirred-tank bioreactor that contains an acclimated microbial culture maintained under aerobic conditions. The aerobic, suspended-growth environment is maintained by diffused aeration, which continuously mixes the bioreactor's contents, which are known collectively as mixed liquor. The mixed liquor is retained in the bioreactor for sufficient time to allow the microorganisms to metabolize the biodegradable organic contaminants into innocuous end-products and intermediate by-products.

The mixed liquor is pumped from the bioreactor into the pressure-driven ultrafiltration module. The ultrafiltration module consists of eight 1-inch-diameter tubes connected in series and contained in a 12-foot by 4-inch-diameter polyvinyl chloride (PVC) housing (Figure 1-2). The tubes support the ultrafiltration membrane, which filters some of the dissolved contaminants and all suspended solids from the mixed liquor.

The continuous flow of mixed liquor, primarily consisting of suspended solids, forms a gel layer on the membrane's surface. Particles from the gel layer are detached by the cross-flow water movement and recirculated into the bioreactor. The unfiltered fraction of the mixed liquor (the concentrate) also is recycled into the bioreactor so that higher-molecular-weight organic compounds are further degraded and the necessary microorganism concentration is maintained for efficient operation. The filtered effluent (the permeate) flows through optional activated carbon

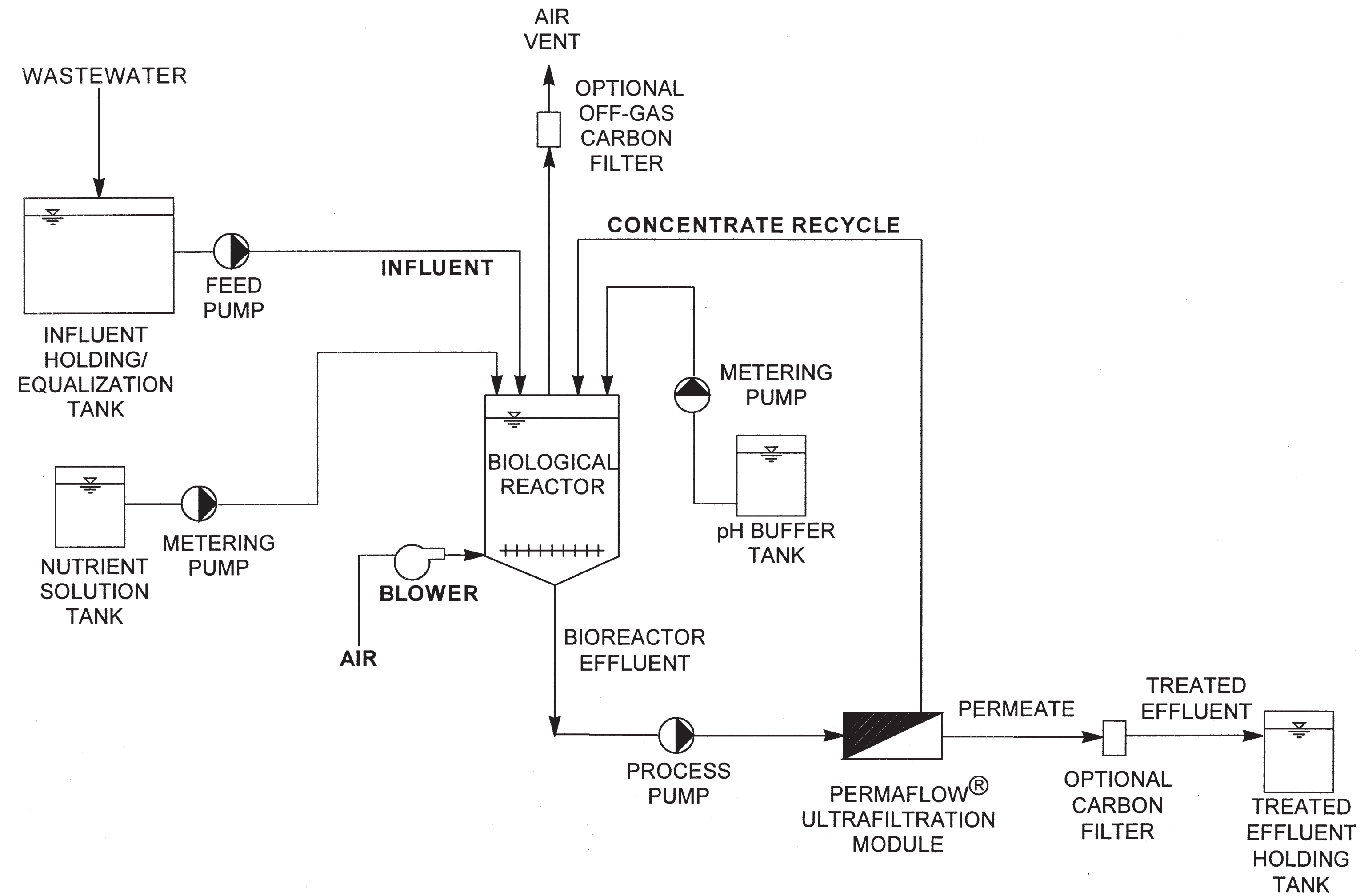


Figure 1-1. ZenoGem system.

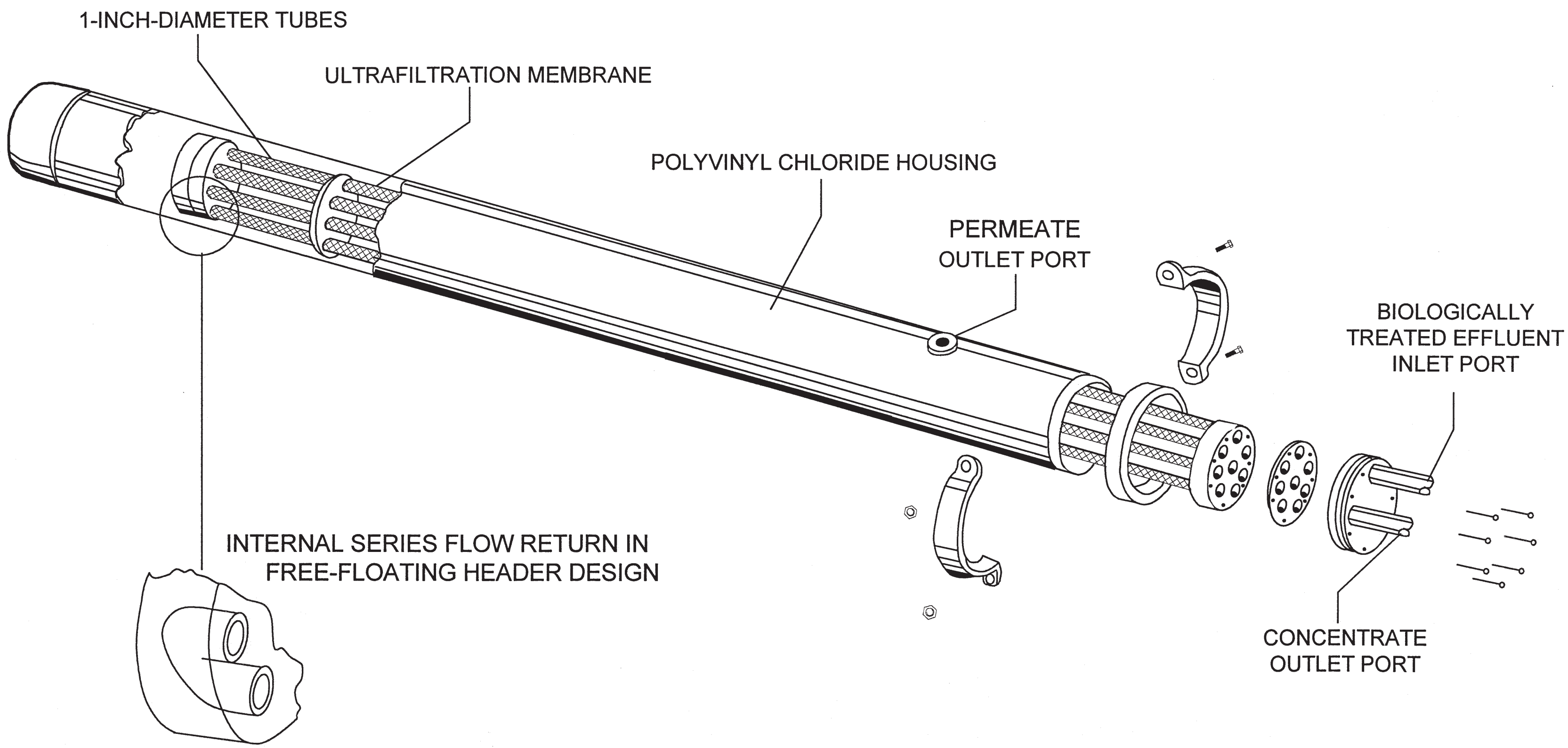


Figure 1-2. ZENON PermaFlow® ultrafiltration module.

filters to remove any nonbiodegradable and trace organic compounds before final treated effluent is discharged.

1.4 Overview and Objectives of the SITE Demonstration

This section provides an overview of the demonstration site and SITE Program demonstration objectives and procedures.

1.4.1 Description of Nascolite Site

The SITE Program demonstration of the ZenoGem® technology was conducted at the Nascolite site in Millville, Cumberland County, New Jersey. Nascolite manufactured acrylate plastic sheets at the site from 1953 to 1980. The company used methyl methacrylate (MMA) monomer as a raw material and operated a MMA reclamation process. Solid acrylic, liquids, and resins containing MMA were purchased from outside sources. These materials were processed through depolymerization, using a molten lead bath followed by distillation and purification. Waste residue from the distillation processes was stored in several underground storage tanks in the northern plant area. In 1985, a remedial investigation and feasibility study (RI/FS) at the Nascolite site revealed that groundwater was contaminated with MMA, various other target compound list (TCL) volatile organic compounds (VOC), and heavy metals. Table 1-1 presents groundwater characterization data for the Nascolite site.

1.4.2 SITE Demonstration Objectives

EPA established primary and secondary objectives for the SITE demonstration of the ZenoGem® technology. The objectives were based on EPA's understanding of the technology, SITE Demonstration Program goals, and input from Zenon. Primary objectives were considered critical for the technology evaluation, while secondary objectives involved collecting additional data considered useful, but not critical to the process evaluation. The demonstration objectives were defined in the EPA-approved QAPP dated November 1994 (EPA 1994). The objectives were selected to provide potential users of the ZenoGem® technology with technical information to determine if the technology is applicable to other contaminated sites. The SITE demonstration was designed to address one primary objective and two secondary objectives for evaluation of the ZenoGem® technology.

Primary Objective

The following was the primary (P) objective of the technology demonstration:

- P1 - Determine if the ZenoGem® treatment system (integrating the bioreactor and ultrafiltration unit as a whole) can achieve a 95 percent or greater removal efficiency for MMA and TCL VOCs and reduce chemical oxygen demand (COD) at a 95 percent confidence level.

The primary objective addressed the biodegradation of TCL VOCs. For the SITE demonstration, critical TCL VOCs were MMA, vinyl chloride, benzene, toluene, ethylbenzene, cis-1,2-dichloroethene, trans-1,2-dichloroethene, trichloroethene, acetone, carbon disulfide, and styrene. These TCL VOCs were chosen as critical parameters because they have been previously detected in the Nascolite site groundwater at significant concentrations.

Secondary Objectives

The following were the secondary (Sc) objectives of the demonstration:

- Sc1 - Evaluate system performance by measuring system parameters that will provide data on operating ranges, reliability, variability, cost-effectiveness, and full-scale remediation potential.

- Sc2 - Estimate approximate capital and O&M costs for the demonstration and for full-scale remediation.

Critical measurements consisted of sample analyses and process measurements that directly impacted meeting the project's primary technical objective. Critical measurements included collection of (1) liquid and air samples for MMA and TCL VOC analyses; (2) liquid samples to evaluate COD; and (3) flow rate measurements of the influent and effluent liquid streams. Flow rate measurements were used to calculate the ZenoGem® system's total reduction of MMA, TCL VOCs, and COD concentrations between the influent and effluent streams.

Noncritical, or system condition measurements, provided information on operating ranges, reliability, variability, cost-effectiveness, and full-scale remediation potential of the technology. System measurements included sample collection and laboratory analyses for the following: total suspended solids (TSS), volatile suspended solids (VSS),

Table 1-1. Maximum Concentrations of TCL VOCs Detected in Groundwater at the Nascolite Site

Contaminant	Maximum Concentration (μg/L)
MMA	398,000
Benzene	400
Toluene	1,100
Ethylbenzene	7,300
cis-1,2-Dichloroethene	540
trans-1,2-Dichloroethene	540
Trichloroethene	460
Total vinyl/methylene chloride	19,200
Total xylene	150
Acetone	1,900,000
Carbon disulfide	1,200
Styrene	150

total metals (metals), total organic carbon (TOC), nutrients (ammonia [NH_3], nitrate/nitrite [NO_3^-/NO_2^-], and phosphate [PO_4^{-3}]), oxygen (O_2), and carbon dioxide (CO_2). System measurements also included measurements for pH, dissolved oxygen (DO), temperature, oxidation/reduction potential (ORP), and specific gravity.

To monitor the ZenoGem® technology, process measurements were collected from various points in the system. The process measurements included flow rates of aqueous and gaseous streams, tank levels within the system and outside the system, and power consumption readings. Gaseous and aqueous flow rates were considered critical parameters. All other process measurements were considered noncritical. Figure 1-3 presents a schematic showing sampling and measurement locations for the ZenoGem® technology.

Information regarding the specific purpose of each demonstration objective, and a summary of the sampling locations and analytical parameters used to support each objective, are presented in Table 1-2.

1.4.3 Demonstration Procedures

The SITE Program evaluated the treatment technology's effectiveness over a period of about 3 months by collecting independent data. Data collection procedures for the demonstration were specified in the EPA-approved QAPP written specifically for the ZenoGem® technology demonstration (EPA 1994).

Predemonstration activities included drilling of four soil borings and subsequent installation of groundwater recovery wells to pump contaminated groundwater to the ZenoGem® system. The wells were equipped with individual peristaltic pumps for evacuating and transferring groundwater from the wells to a equalization tank. Groundwater in the equalization tank was periodically sampled during pumping operations and analyzed for MMA concentration using an on-site gas chromatograph (GC). The analytical results were used to determine if the groundwater required dilution to achieve the influent target MMA concentration of 2,500 milligrams per liter (mg/L). When analytical results confirmed that the MMA concentration was slightly greater than 2,500 mg/L, the groundwater was pumped to a 5,000-gallon tanker, and through a piping network into the system for treatment.

After the ZenoGem® system was installed, Zenon performed a series of technology checks which included (1) conducting a leak test of technology components and process pipes, (2) verifying that component safety switches were operating accurately, and (3) calibrating flow meters and metering pumps. For the leak test, Zenon initially filled the bioreactor with about 600 gallons of potable water which was pumped through the entire treatment process to ensure the technology was operating

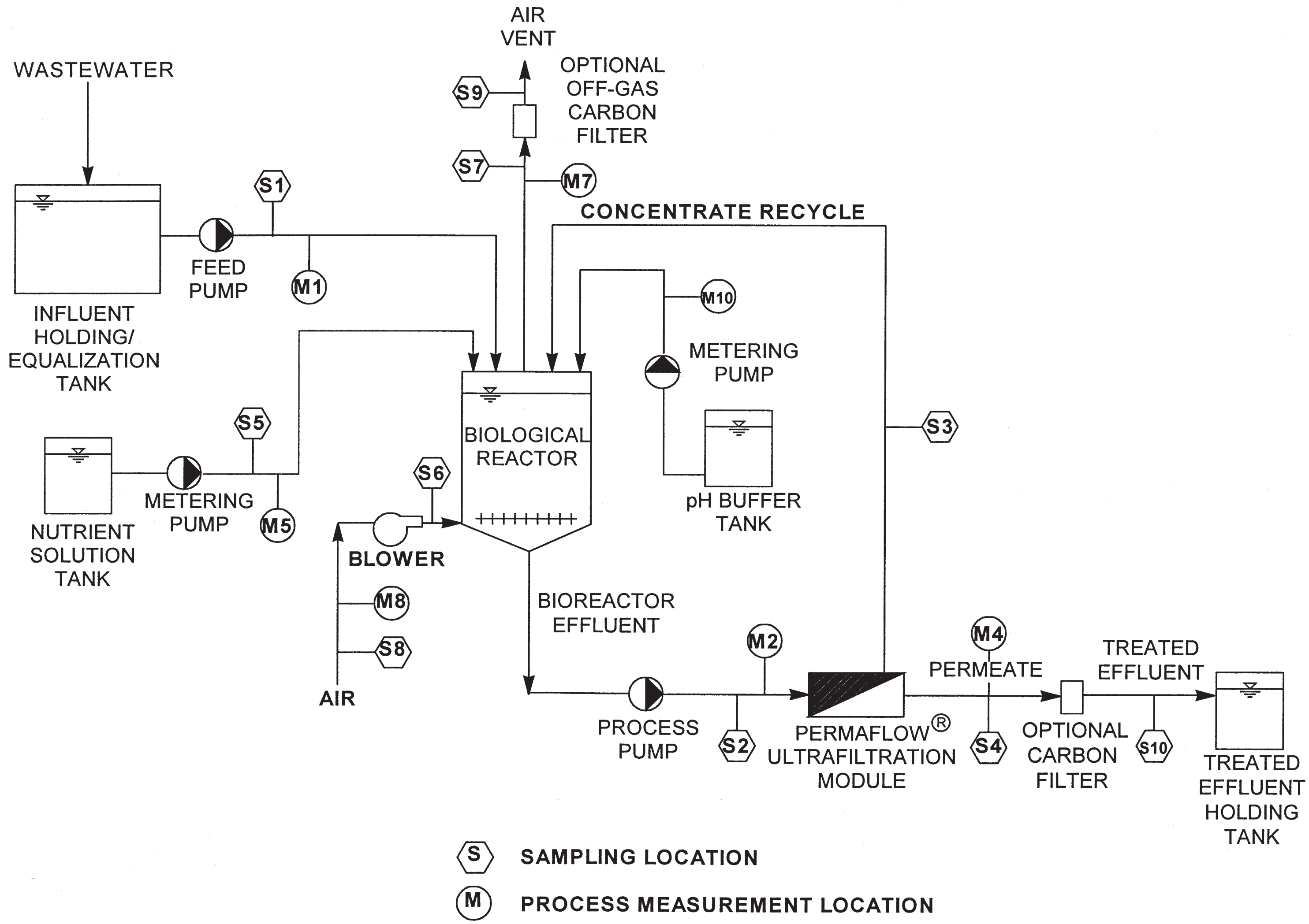


Figure 1-3. Sampling locations.

Table 1-2. Analytical Measurement Parameters and Relationship to Project Objectives

Matrix	Sampling Location	Parameter	Class	Objective
Feed Influent	S-1	TCL VOCs+MMA, COD, Flow Rate	Critical	P1, Sc1, Sc2
		pH, TSS, VSS, DO, temperature, metals, TOC, ORP, sg, NO_3^-/NO_2^-, NH_3, PO_4^{-3}	Noncritical	Sc1, Sc2
Bioreactor Effluent	S-2	TCL VOCs+MMA, COD	Critical	P1, Sc1
		pH, TSS, VSS, DO, temperature, metals, TOC, ORP, sg, NO_3^-/NO_2^-, NH_3, PO_4^{-3}, Flow Rate	Noncritical Critical	Sc1 P1
Concentrate Recycle	S-3	TCL VOCs+MMA, COD	Critical	P1, Sc1
		pH, TSS, VSS, DO, temperature, metals, TOC, ORP, sg, NO_3^-/NO_2^-, NH_3, PO_4^{-3}, Flow Rate	Noncritical	Sc1
Permeate Effluent	S-4	TCL VOCs+MMA, COD, Flow Rate	Critical	P1, Sc1, Sc2
		pH, TSS, VSS, DO, temperature, metals, TOC, ORP, sg, NO_3^-/NO_2^-, NH_3, PO_4^{-3}	Noncritical	Sc1
Treated Effluent	S-10	TCL VOCs+MMA, COD	Critical	P1, Sc1
		pH, TSS, VSS, DO, metals, TOC, ORP, sg, NO_3^-/NO_2^-, NH_3, PO_4^{-3}	Noncritical	Sc1
Nutrient Feed	S-5	NO_3^-/NO_2^-, NH_3, PO_4^{-3}, sg, Flow Rate	Noncritical	Sc1, Sc2
Bioreactor Inlet Gas	S-6	TCL VOCs+MMA, Flow Rate	Critical	P1, Sc1
		O_2, CO_2	Noncritical	Sc1
Bioreactor Outlet Gas	S-7	TCL VOCs+MMA, Flow Rate	Critical	P1, Sc1
		O_2, CO_2	Noncritical	Sc1
Bioreactor Outlet Gas (after carbon)	S-9	TCL VOCs+MMA, Flow Rate	Critical	P1, Sc1
Air Inlet	S-8	TCL VOCs+MMA, O_2, CO_2, Flow Rate	Noncritical	Sc1

properly. During the test, SITE Program personnel did not observe any leaks and Zenon confirmed that the component safety switches were operating correctly.

Zenon seeded the bioreactor by pumping into it 500 gallons of sludge obtained from the local publicly owned treatment works (POTW). Zenon then added 5 gallons of MMA-acclimated sludge to the bioreactor. Zenon cultivated the biomass to obtain a maximum microbial growth while maintaining a minimum toxic shock to the microorganisms. In addition, Zenon periodically added powdered milk and wheat flour as food sources for the microorganisms until the contaminated groundwater was available for treatment.

A start-up run was conducted prior to beginning the demonstration run. The purpose of the start-up run was to identify and resolve any problems that arose from technology operation or sampling and field protocols. No samples were sent for off-site analysis during the start-up run. The initial effluent flow rate of the treatment system established for the entire demonstration was 720 gallons per day.

1.5 KEY CONTACTS

Additional information on the ZenoGem® biological and ultrafiltration technology, Zenon, the SITE Program, and the Nascolite site is available from the following sources:

EPA Project Manager
Daniel Sullivan
U.S. Environmental Protection Agency (MS-104)
National Risk Management Research Laboratory
2890 Woodbridge Avenue, Building 10
Edison, NJ 08837-3679
908/321-6677

Technology Developer
F. Anthony Tonelli
Zenon Environmental Inc.
845 Harrington Court
Burlington, Ontario, Canada L7N 3P3
905/639-6320

Information on the SITE program is available through the following on-line information clearinghouse: the Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) database contains information on 154 technologies offered by 97 developers.

Technical reports may be obtained by contacting U. S. EPA/NCEPI, P. O. Box 42419, Cincinnati, Ohio 45242-2419, or by calling 800-490-9198.

Section 2
Technology Effectiveness Analysis

This section addresses the effectiveness of the ZenoGem® technology for treating groundwater contaminated with MMA and TCL VOCs. This evaluation of the technology's effectiveness is based on the results of the SITE demonstration at the Nascolite site.

Vendor claims and case studies regarding the effectiveness of the ZenoGem® biological and ultrafiltration technology are presented in Appendix A. Tables summarizing the field and laboratory analytical data for samples collected during the demonstration are included in Appendices B and C, respectively.

2.1 SITE Demonstration Results

This section summarizes the results from the SITE demonstration of the ZenoGem® technology for both critical and noncritical parameters, and is organized according to the project objectives stated in Section 1.4.2. Section 2.1.1 addresses the primary objective, and Section 2.1.2 address secondary objectives.

The ZenoGem® technology treated about 47,200 gallons of groundwater contaminated with MMA, at flow rates ranging from 380 to 620 gpd. As shown in tables B-4 and B-5 in Appendix B, the total inflow to the treatment system was significantly less than the total outflow from the system. According to Zenon, the difference in these values may be due to the effluent flow meter recording the permeate that was at times being recirculated back to the bioreactor. Zenon periodically recirculates the permeate when making process adjustments prior to discharge from the system. The demonstration consisted of continuous operation over a 3-month period, during which influent MMA concentrations varied from 567 mg/L to 9,500 mg/L.

For the last 3 weeks of the demonstration, the technology was evaluated under an approximate three-fold increase in contaminant concentration shock-loading, which increased the influent MMA concentration from 2,360 mg/L to 7,140 mg/L (Figure 2-1). During the first 4 hours of the test, the influent MMA concentrations were increased while the feed rate remained at 720 gpd, creating a short-term organic shock-load to the microorganisms in the bioreactor. After 4 hours, the feed flow rate was decreased to 50 gpd, and then increased to 140 gpd to maintain a constant volumetric organic loading throughout the remainder of the demonstration.

2.1.1 Objective P-1: Removal Efficiencies

This section describes demonstration removal efficiencies for MMA, TCL VOCs, and COD. Removal efficiencies for each compound or parameter was evaluated over the 3-month demonstration (September, October, and November). In cases where effluent concentrations of a compound were nondetectable, the detection limit value (for example 0.01 mg/L for MMA), rather than an assumed concentration of 0.00 mg/L, was used to calculate the minimum removal efficiency. This conservative practice was adopted to ensure that the removal efficiency would not be overestimated, and assumes that a compound not detected in the effluent at 0.01 mg/L may have been present at a concentration between 0.00 mg/L and 0.01 mg/L. For this reason, the removal efficiencies values for the compounds and parameters are the minimum possible values and may be lower than the actual removal efficiencies achieved by the system.

MMA Results

Effluent MMA concentrations during the demonstration varied from less than the detection limit of 0.01 mg/L to 16.8 mg/L in the permeate stream (S-4). As shown in Figure 2-2, the permeate MMA removal efficiencies during the demonstration consistently surpassed the

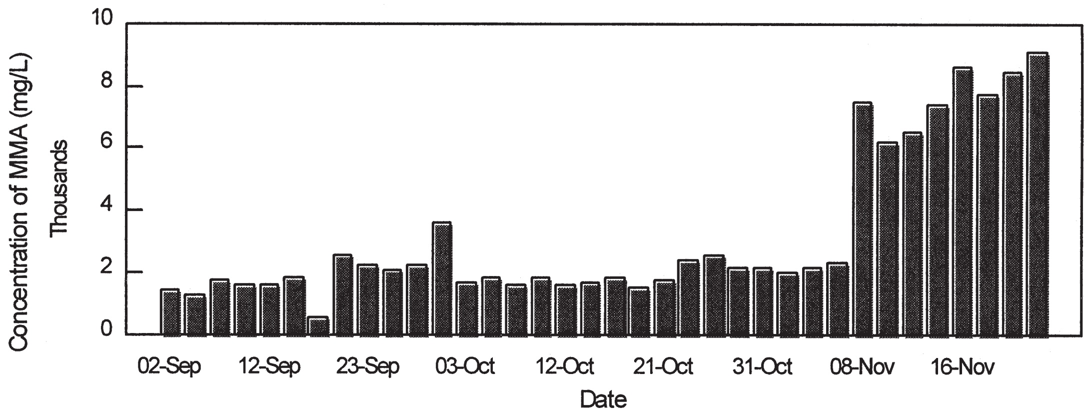


Figure 2-1. Total MMA concentrations in influent stream (S-1).

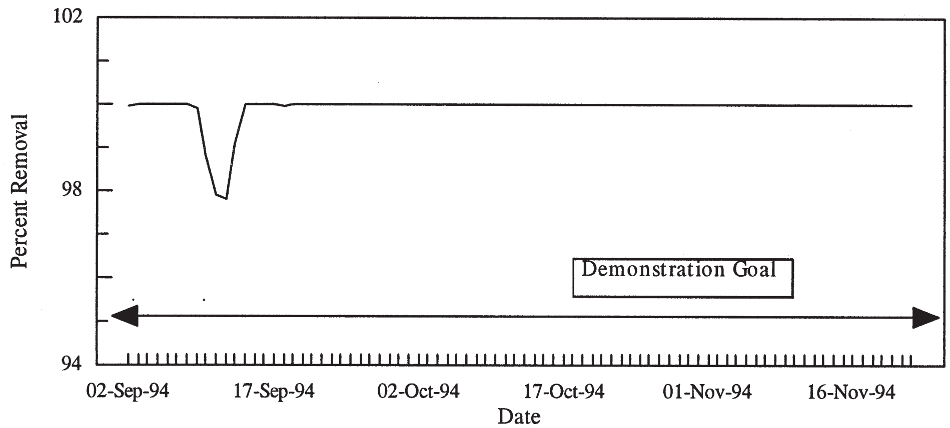


Figure 2-2. Removal efficiency (MMA + VOCs) (S-4).

demonstration goal of 95 percent reduction. The average removal efficiency for MMA was greater than 99.98 $\pm$ 0.01 percent for the 3 month demonstration. Beginning in week 7, additional samples were collected for MMA analyses from the treated effluent stream (S-10) following the permeate carbon filters. The permeate carbon filters were originally installed to prevent possible trace contaminants from discharging to the treated effluent holding tank. MMA concentration in the treated effluent following carbon filtration ranged from less than 0.02 mg/L to 0.29 mg/L, improving the average removal efficiency of the system to 99.9 $\pm$ 0.01 percent. The high removal efficiency for MMA also was maintained after a 3-fold concentration was delivered to the system (shock loading test), suggesting that a sudden increase in influent MMA concentration had little noticeable effect on the technology's performance.

The majority of analytical data for samples collected from S-4 were below the detection level of 0.01 mg/L. However, the analytical data for samples collected from S-4 on September 11 through 13 (about 2 weeks into treatment) were about 1,000 times greater than the remainder of the demonstration. This was inconsistant with the data collected throughout the demonstration, and do not appear to be representative of actual treated effluent concentrations. For example, as shown in Table C-1 in Appendix C, the MMA concentration in the effluent after September 13 was below or slighty above the detection limit of 0.01 mg/L. Although the cause of the increase is unknown, occasionally a low population of microorganisms will result in a low initial degradation rate that will increase after the microogranisms are allowed to acclimate for a period of a few days. This finding is not considered significant since (1) the temporary increase in MMA concentration was maintained for only three days, and (2) the goal of a 95 perent reduction was maintained by the system throughout the 3-month demonstration.

TCL VOC Results

TCL VOCs analyzed in samples collected from the influent and effluent streams during the demonstration included vinyl chloride, benzene, trans-1,2-dichloroethene, trichloroethene, acetone, carbon disulfide, ethylbenzene, toluene, and styrene. The laboratory reported all other quantified analytes from the TCL; however, tentatively identified compounds were not reported.

Due to the high MMA concentrations in the influent, the laboratory was unable to analyze aqueous TCL VOC samples at a low enough dilution factor to quantify the low concentrations of TCL VOCs without overloading the GC. Most TCL VOC detection limits in the influent ranged from about 2,500 to 500,000 micrograms per liter (μg/L), depending on the dilution ratio. In samples that had detection limits this high, no targeted TCL VOCs were above detection limits in the influent stream (S-1). Detection limits were low enough in only five of the 71 samples collected to quantify TCL VOC concentrations. Consequently, removal efficiencies for individual TCL VOCs could not be calculated for the majority of the samples collected during the demonstration.

Table 2-1 compares the five influent samples with reportable TCL VOC concentrations in samples collected from sampling port S-1 to the corresponding TCL VOC concentrations in samples collected from sampling port S-4. Reductions of greater than 97 percent were noted in all TCL VOCs reported.

Mass Balance

The primary objective (P1) of the demonstration was to show that the ZenoGem® process was able to achieve 95 percent removal efficiency of the total influent mass of MMA and TCL VOCs (EPA 1994), using the following equation:

$$\%RE = \frac{(MMA+VOC)_I - (MMA+VOC)}{(MMA+VOC)_I} \times 100$$

where:

%RE = Removal efficiency
$(MMA + VOC)_I$ = Total mass in influent stream
(MMA + VOC) = Total mass in effluent stream

Total influent mass was calculated from the daily MMA and TCL VOC concentrations in the influent stream (S-1) and the average of the three daily flow measurements, collected at measurement location M-1, multiplied over a 24-hour period, accounting for periods when the system was not operating. Effluent mass was calculated from the S-4 and S-10 streams in the same manner.

The following equation was used to calculate the total mass of MMA and TCL VOCs for both the influent and effluent streams:

$$M_{(MMA+VOC)} = \sum_{i=1}^{83} Q_i[x_i]$$

where:

$M_{(MMA+VOC)}$ = Total mass of MMA and TCL VOCs
Q_i= Average daily flow, in liters
$[x_i]$ = Daily MMA+TCL VOC concentration (mg/L)
83 = Number of samples

Based on extrapolation from the sample concentration data and flow meter readings, the total mass of MMA and TCL VOCs entering the system during the demonstration was about 561,000 grams and the mass of MMA and TCL VOCs leaving the system after treatment was about 196 grams. Therefore, total mass of MMA and TCL VOCs in the effluent prior to carbon polishing was reduced at least 99.96 percent. The actual mass reduction may have been greater, but was indeterminable because the total mass of TCL VOCs entering the system could not be determined due to the elevated detection limits. Table 2-1 indicates that the average TCL VOC concentration in the influent was likely to be several orders of magnitude lower than the MMA concentration, and thus should have contributed only a negligible amount to the total influent mass of the contaminants.

To determine if volatilization to air contributed significantly to the observed mass reduction efficiency, the quantity of MMA (Figure 2-3) and TCL VOCs (Figure 2-4) lost through the emissions stream (S7) were determined using the daily air flow measurements (Figure 2-5) collected at measurement location M7 and the analytical results of the biweekly air sample. As shown in Figures 2-3 and 2-4, an increase in MMA and TCL VOCs concentrations occurred on the first day of the shock-loading test and then decreased throughout the remainder of the demonstration.

Table 2-1. Measured TCL VOC Reductions

Sampling Date	TCL VOC Compound	Influent Concentration (S-1)	Permeate Concentration (S-4)	Percent Reduction[a]
9/5/94	Methylene chloride	636	8.85	98.6
	Trichloroethene	852	1.75J	99.8
	Benzene	282J	5.0U	>98.2
9/6/94	Methylene chloride	618	11.6	98.1
	Trichloroethene	905	5.0U	>99.4
	Benzene	279J	5.0U	>98.2
	Toluene	105J	5.0U	>95.2
9/16/94	Methylene chloride	500J	11.2	97.8
10/1/94	Methylene chloride	15,300	5.0U	>99.3
10/11/94	Xylenes	14,400J	5.0U	>99.9

Notes:

[a] Percent reduction measured from permeate stream prior to carbon polishing.
All concentrations in micrograms per liter (μg/L).
J = Compound concentration is estimated. Value is below sample detection limit.
U = Compound was not detected. Associated number is the sample detection limit.

Figure 2-5 shows that the daily air flow measurement remained relatively low (less than 5 scfm) during Sepetember compaired to the remainder of the demonstration (about 12 scfm). Although the cause of the fluctuation in air flow is unknown, Zenon has process capability to control the amount of oxygen supplied to the bioreactor to maintain organism growth and degradation of the organic compounds. This finding is not considered significant since the goal of a 95 perent reduction was maintained by the system throughout the 3-month demonstration.

The total mass loss for each compound over the demonstration was calculated by the following:

$$M_{(x)} = \sum_{i=1}^{83} \frac{kQ_i[x_i]m_x}{22.4}$$

where:

$M_{(x)}$ = Total mass of compound *x* in grams
Q_i = Air flow for i^{th} day, in standard cubic feet (scf)
$[x_i]$ = Volumetric concentration of compound *x* in liters
m_x = Molecular weight of compound *x* in grams/mole
k = Conversion factor
83 = number of samples

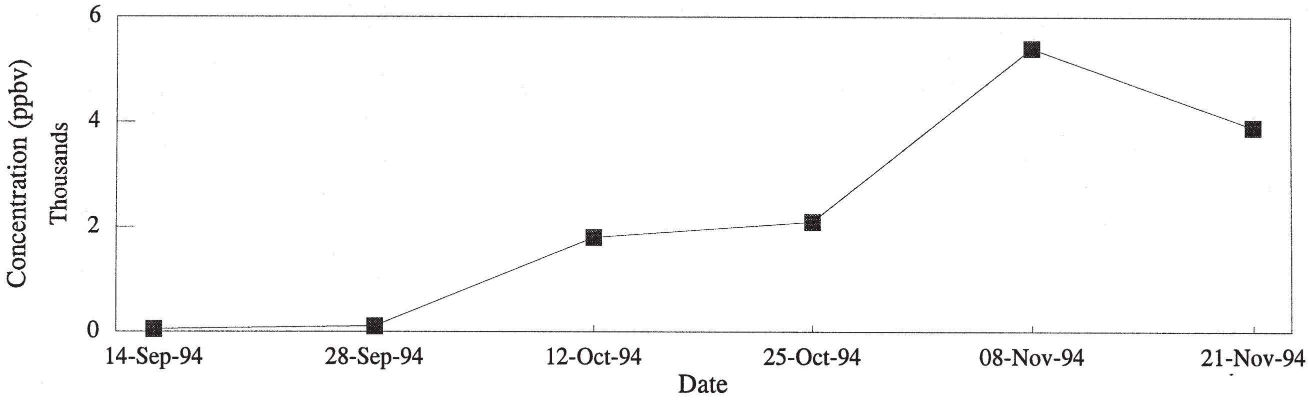


Figure 2-3. MMA in air (S-7).

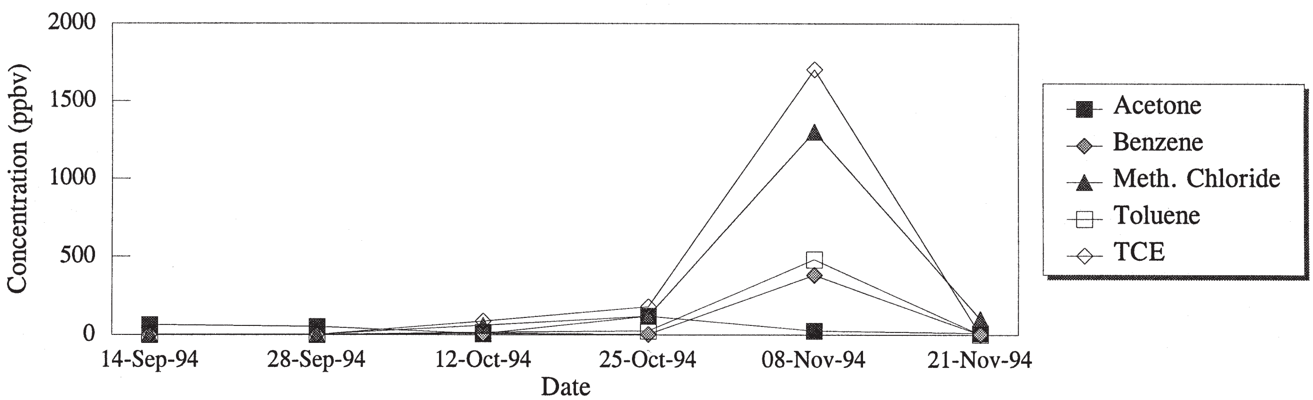


Figure 2-4. VOCs in air (S-7).

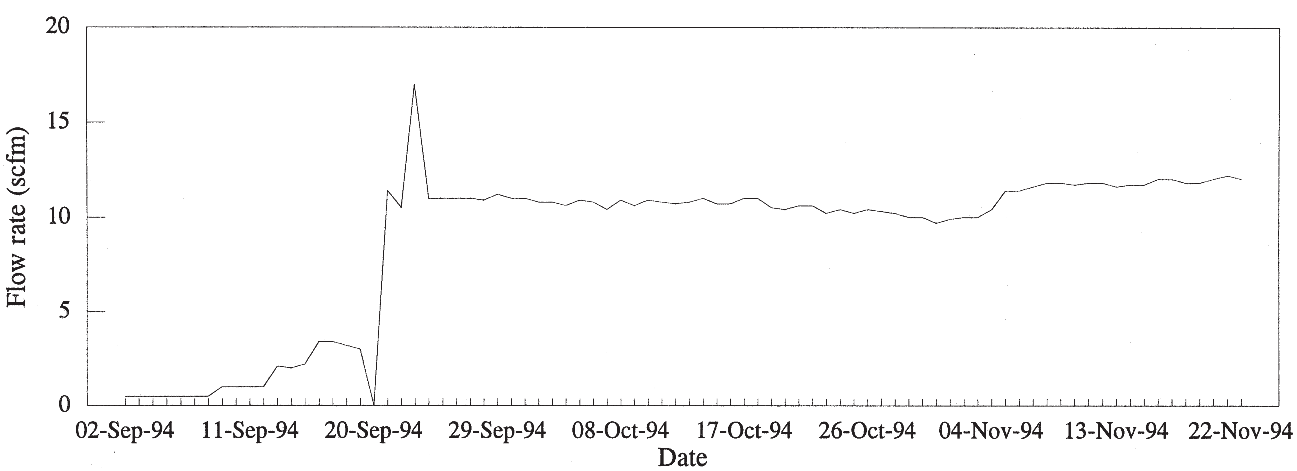


Figure 2-5. Air flow in emission stream (S-7).

Mass was computed for an ideal gas at standard temperature and pressure (STP). Daily flow volume was determined by using the average of the three daily air measurements (in standard cubic feet per minute [scfm]) and multiplying over a 24-hour period, accounting for periods when the system was temporarily shutdown. The daily volumetric concentration of each compound was calculated by interpolation from the biweekly analytical results.

Based on extrapolation from the air sample concentration data and the flow meter readings, the total volatilization of MMA and TCL VOCs from the system was calculated at about 411 grams. This values represents less than 0.10 percent of the total MMA and TCL VOC mass treated during the demonstration.

COD Results

During the course of the demonstration, influent COD concentrations varied from 1,490 mg/L to 13,600 mg/L. COD concentrations in the permeate (S-4) varied from 10.3 mg/L to 1,880 mg/L, and COD concentrations in the treated effluent stream (S-10) ranged from 56.0 mg/L to 1,090 mg/L. Figure 2-6 shows the removal efficiencies for the permeate stream (S-4). Based on these data, reduction efficiencies for COD calculated for the permeate stream (S-4) varied from 84.7 percent to 95.6 percent, yielding an overall COD reduction efficiency of 88.6 $\pm$ 8.4 percent. Data for the S-10 treated, or final, effluent stream was not generated until week 7 of the demonstration. Figure 2-7 shows the reduction efficiencies for the treated effluent stream (S-10). During 4 out of the 5 weeks, the reduction efficiencies in the effluent were above the 95 percent demonstration goal and averaged 96.8 $\pm$ 5.01 percent.

Figure 2-8 compares the reduction efficiencies for the permeate stream (S-4) with those observed in the treated effluent stream (S-10).

During the last 3 weeks of the demonstration, the system was evaluated under an approximate three-fold increase in contaminant concentration shock-loading, which instantaneously increased the influent COD concentrations from 6,400 mg/L to 19,600 mg/L. During the first 4 hours of the test, the influent COD concentrations were increased while the feed rate remained at 720 gpd, creating a short-term, organic shock-load to the microorganisms in the bioreactor. After 4 hours, the flow rates were decreased to 50 gpd, and then increased to 140 gpd to maintain a consistent volumetric organic loading throughout the remainder of the demonstration. The treated effluent (S-10) reduction efficiency for COD following the shock loading was calculated at 98.8 $\pm$ 0.64 percent.

2.1.2 Objective S-1: Total Metals, TSS, VSS, TOC, ORP, sg, DO, Temperature, pH, Nutrients

This section presents the results of measurements for secondary parameters of interest for the demonstration.

Metals

Table 2-2 summarizes the average aluminum, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc concentrations detected in the influent (S-1), permeate (S-4), and treated effluent (S-10) streams. As shown in Figures 2-9 through 2-18, the concentration of metals in the S-1 stream exhibited substantially higher concentrations than that detected in the S-4 and S-10 streams, with the exception of some sample results that are anomalous. Metal concentrations increased throughout the demonstration in the bioreactor effluent (S-2) and the concentrate stream (S-3). This indicates that the majority of metals in the S-1 stream were retained and accumulated throughout the demonstration with the exception of a small percentage of the metals that passed through the ultrafiltration module and were detected in the permeate and treated effluent streams. At these concentrations, the metals did not appear to inhibit the microorganisms degradation rate for MMA and TCL VOCs. Depending on wastewater characteristics, pretreatment can be incorporated into the treatment train to reduce metal accumulation in the system.

TSS

Figure 2-19 shows the TSS concentrations measured in the influent (S-1), permeate (S-4), and treated effluent (S-10) streams during the demonstration. The TSS concentration in the influent stream exhibited higher concentrations than that detected in the permeate and treated effluent streams. On November 12, the influent TSS concentration increased from 43 mg/L to 19,000 mg/L. Although the cause of this anomalous value is unknown, the increase in concentration may be due to not thoroughly mixing the groundwater in the holding tank prior to transferring to the

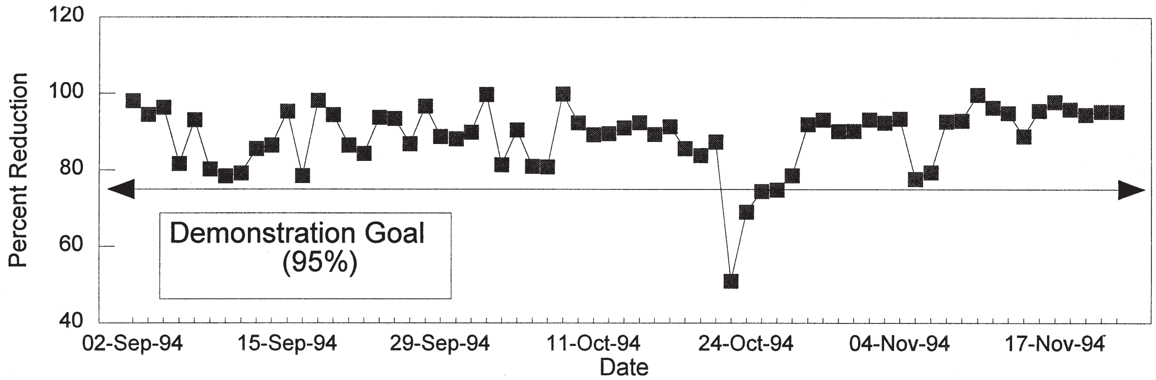


Figure 2-6. COD removal efficiency (S-4).

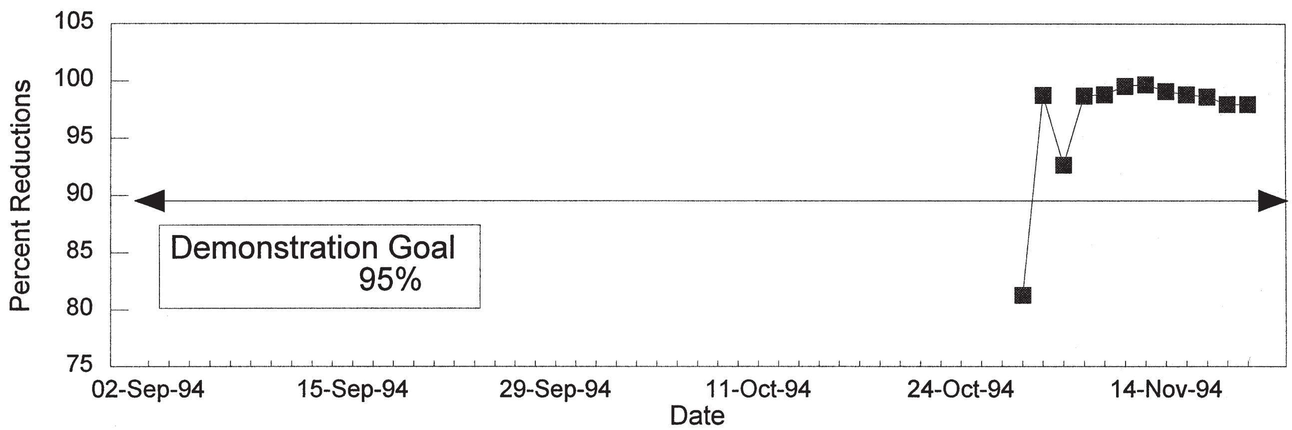


Figure 2-7. COD removal efficiency (S-10).

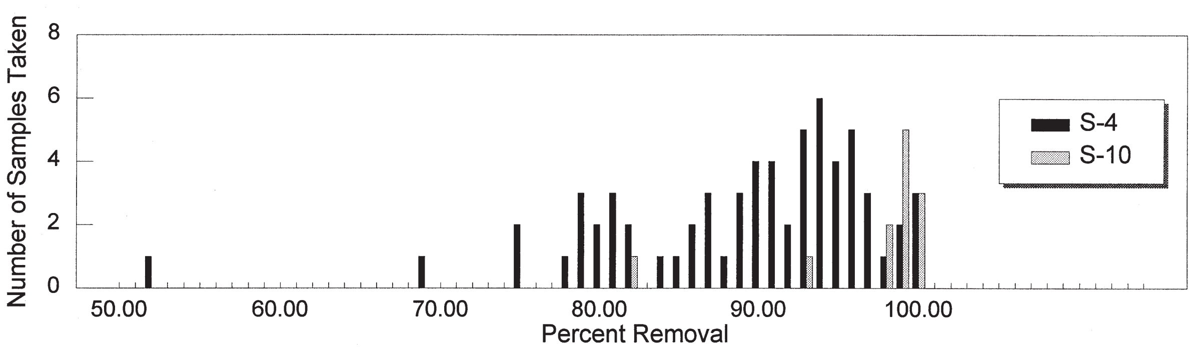
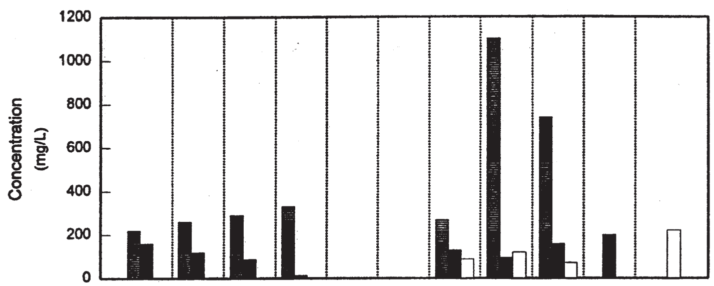


Figure 2-8. Distribution of COD removal efficiency by number of samples (S-4 and S-10).

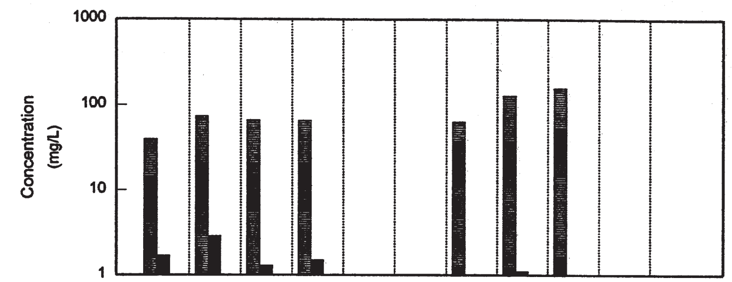
Table 2-2. Total Metals Concentrations

Metal	Influent Stream S-1	Permeate Stream S-4	Treated Effluent Stream S-10	Influent Stream S-1 Concentration Range	Permeate Stream S-4 Concentration Range	Treated Effluent Stream S-10 Concentration Range
Aluminum	514	106	65.7	220-1,100	12.8-160	0.07-120
Cadmium	82.7	1.62	---	40-150	1.1-2.9	0.8
Chromium	8.3	2.9	---	3.5-16	0.08-5.6	5.3
Copper	6.86	4.8	3.9	3.1-8.5	0.9-9.8	0.01-9.7
Iron	21,400	149	28.6	9800-36,500	40-220	0.04-59
Lead	222	10.5	11.1	110-330	3.6-16	9.1-13
Manganese	170	32.2	10.2	84-290	7.9-60	0.01-27
Mercury	0.11	1.18	---	0.055-0.13	0.075-3.3	0.042
Nickel	19.3	8.7	2.6	10-31	0.04-36	0.01-5.1
Zinc	2,120	131	29.0	810-4,100	71-240	0.01-51



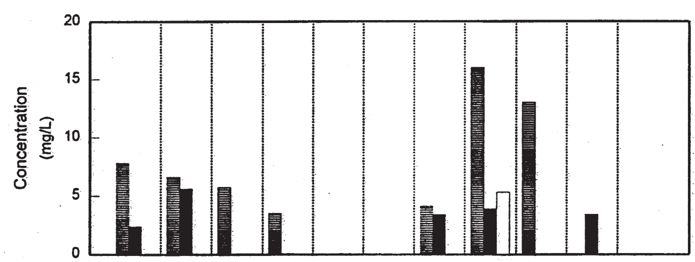
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
■ S1	220	260	290	330	NA	NA	270	1,100	740	NA	NA
■ S-4	160	120	86	12.8	NA	NA	130	94	160	200	NA
□ S-10	NA	NA	NA	NA	0.07	0.14	88	120	71	NA	220

Figure 2-9. Aluminum concentrations in the S-1, S-4, and S-10 streams.



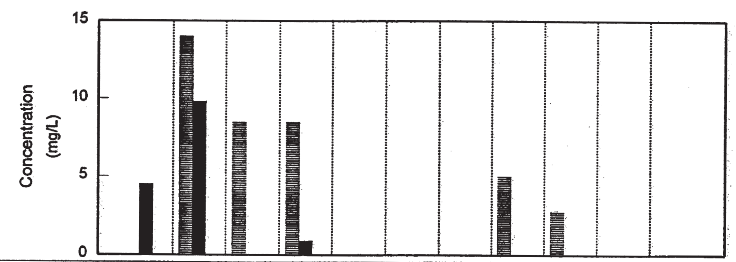
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
■ S-1	40	74	67	66	NA	NA	64	130	160	NA	NA
■ S-4	1.70	2.90	1.30	1.51	NA	NA	ND	1.10	ND	ND	NA
□ S-10	NA	NA	NA	NA	ND	ND	ND	ND	ND	NA	ND

Figure 2-10. Cadmium concentrations in the S-1, S-4, and S-10 streams.



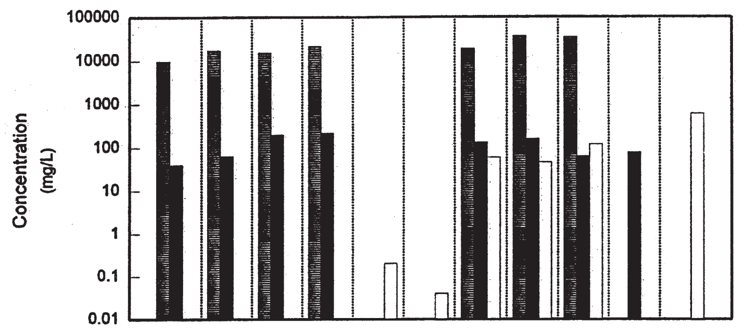
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
▤ S1	7.8	6.6	5.70	3.5	NA	NA	4.1	16	13	NA	NA
■ S4	2.4	5.6	ND	0.08	NA	NA	3.4	3.9	ND	3.4	NA
□ S10	NA	NA	NA	NA	ND	ND	ND	5.3	ND	NA	ND

Figure 2-11. Chromium concentrations in the S-1, S-4, and S-10 streams.



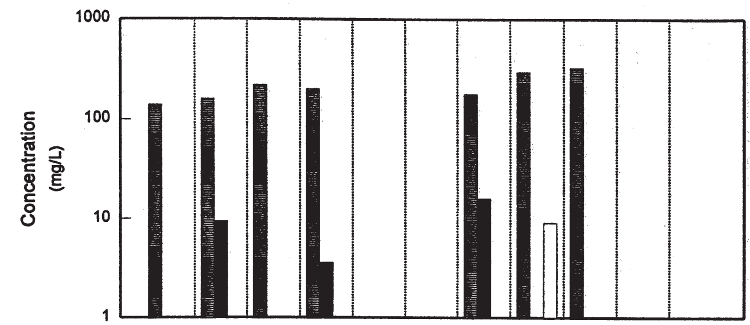
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
▤ S-1	ND	14.0	8.5	8.5	NA	NA	ND	5.0	2.8	NA	NA
■ S-4	4.5	9.8	ND	0.9	NA	NA	ND	ND	ND	ND	NA
□ S-10	NA	NA	NA	NA	0.01	ND	ND	ND	ND	NA	ND

Figure 2-12. Copper concentrations in the S-1, S-4, and S-10 streams.



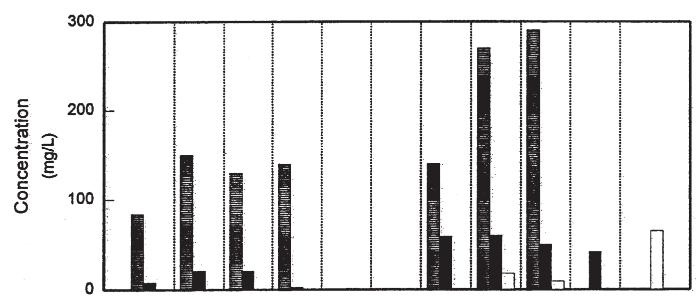
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S1	9,800	17,100	15,400	21,500	NA	NA	18,600	36,500	34,000	NA	NA
S-4	40	64	200	218	NA	NA	130	160	63	78	NA
S-10	NA	NA	NA	NA	0.2	0.04	59	46	120	NA	600

Figure 2-13. Iron concentrations in the S-1, S-4, and S-10 streams.



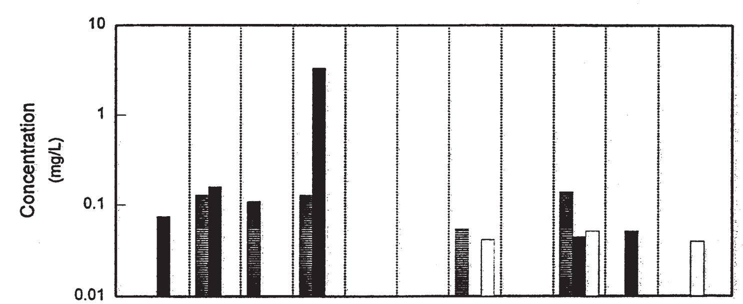
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S-1	140	160	220	200	NA	NA	180	300	330	NA	NA
S-4	ND	9.4	ND	3.6	NA	NA	16	ND	ND	ND	NA
S-10	NA	NA	NA	NA	ND	ND	ND	9.1	ND	NA	ND

Figure 2-14. Lead concentrations in the S-1, S-4, and S-10 streams.



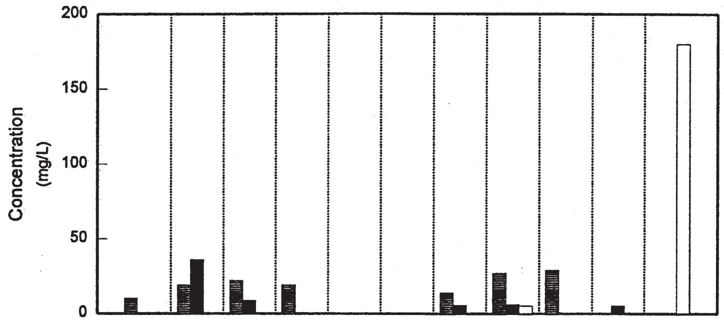
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S1	84	150	130	140	NA	NA	140	270	290	NA	NA
S4	7.9	21	21	2.6	NA	NA	59	60	50	42	NA
S10	NA	NA	NA	NA	0.01	ND	ND	18	9.1	NA	65

Figure 2-15. Manganese concentrations in the S-1, S-4, and S-10 streams.



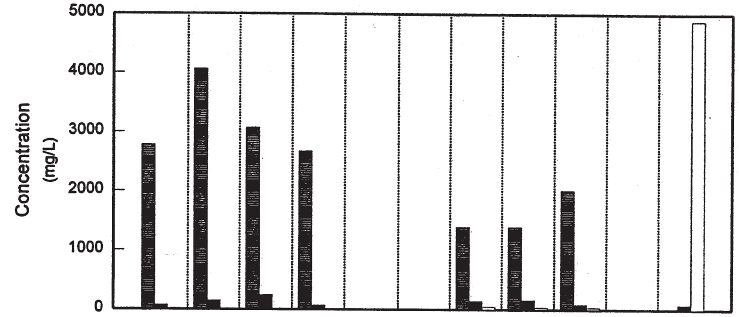
Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S-1	ND	0.130	0.110	0.130	NA	NA	0.055	ND	0.140	NA	NA
S-4	0.075	0.160	ND	3.300	NA	NA	ND	ND	0.045	0.052	NA
S-10	NA	NA	NA	NA	ND	ND	0.042	ND	0.052	NA	0.040

Figure 2-16. Mercury concentrations in the S-1, S-4, and S-10 streams.



Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S1	10	19	22	19	NA	NA	14	27	29	NA	NA
S-4	ND	36.0	8.8	0.04	NA	NA	5.7	6.0	ND	5.0	NA
S-10	NA	NA	NA	NA	0.01	ND	ND	5.1	ND	NA	180

Figure 2-17. Nickel concentrations in the S-1, S-4, and S-10 streams.



Date	02-Sep	16-Sep	30-Sep	14-Oct	20-Oct	27-Oct	28-Oct	08-Nov	09-Nov	23-Nov	28-Nov
S-1	2,780	4,060	3,070	2,680	NA	NA	1,400	1,400	2,020	NA	NA
S-4	71	150	240	70	NA	NA	140	160	86	NA	77
S-10	NA	NA	NA	NA	0.12	0.01	51	38	37	NA	4,880

Figure 2-18. Zinc concentrations in the S-1, S-4, and S-10 streams.

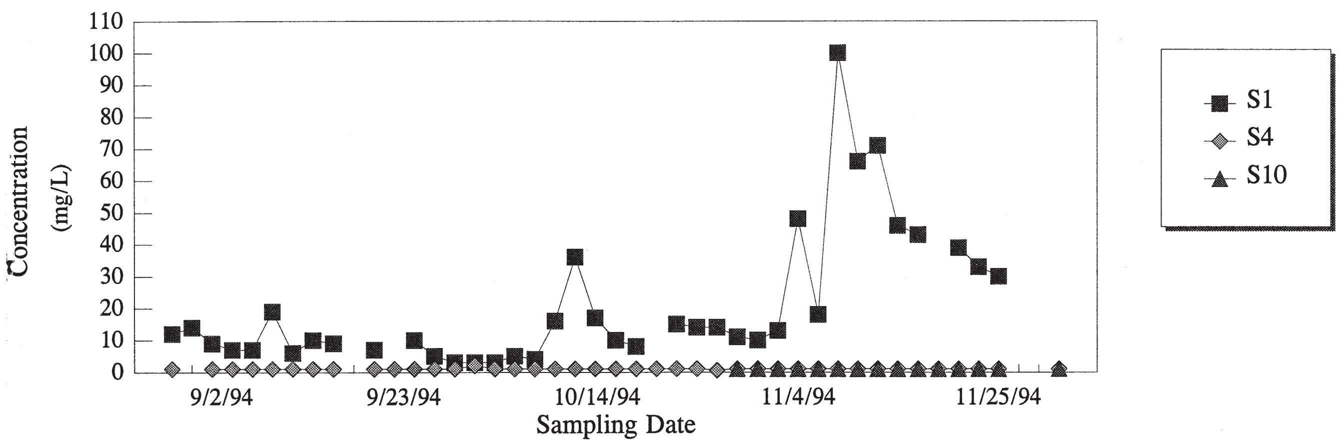


Figure 2-19. TSS concentrations in the S-1, S-4, and S-10 streams.

bioreactor using a submersible pump. This finding is not considered significant since (1) the temporary increase in TSS concentration was maintained for only one day, and (2) the increase in concentration was not reflected in the effluent stream. TSS concentrations increased throughout the demonstration in the bioreactor effluent (S-2) and the concentrate stream (S-3). This indicates that the majority of suspended solids in the influent stream were retained and accumulated in the system throughout the demonstration. The technology demonstrated that the ultrafiltration module was effective in reducing TSS from an average concentration in the influent stream of 507 mg/L to less than 2 mg/L (the detection limit) in the permeate and treated effluent streams, respectively. The TSS removal efficiency was calculated to be 99.7 percent.

VSS

Figure 2-20 shows the VSS concentrations measured in the influent (S-1), permeate (S-4), and treated effluent (S-10) streams during the demonstration. The VSS concentration in the influent stream exhibited higher concentrations than that detected in the permeate and treated effluent streams. On November 12, the influent VSS concentration increased from 34 mg/L to 17,000 mg/L. Although the cause of this anomalous value is unknown, the increase in concentration may be due to not thoroughly mixing the groundwater in the holding tank prior to transfering to the bioreactor using a submersible pump. This finding is not considered significant since (1) the temporary increase in VSS concentration was maintained for only one day, and (2) the increase in concentration was not reflected in the effluent stream. VSS concentrations increased throughout the demonstration in the bioreactor effluent (S-2) and the concentrate stream (S-3). This indicates that the majority of VSS in the influent stream were retained and accumulated in the system during the demonstration. The technology demonstrated that the ultrafiltration module was effective in reducing VSS from an average concentration in the influent stream of 452 mg/L to less than 2 mg/L in the permeate and treated effluent streams, respectively. The VSS removal efficiency was calculated to be 99.7 percent.

TOC

Figure 2-21 shows the TOC concentrations measured in the influent (S-1), permeate (S-4), and treated effluent (S-10) streams during the demonstration. The TOC concentrations in the influent stream exhibited higher concentrations than that detected in the S-4 and S-10 streams, indicating that the concentration of organic matter was reduced in the system. The average TOC concentrations for the S-1, S-4, and S-10 stream was about 1,160 mg/L, 280 mg/L, and 83 mg/L, respectively. The TOC removal efficiencies was calculated for the permeate stream to be 75.9 percent and for the treated effluent stream to be 92.8 percent.

ORP

Figure 2-22 shows the values measured in the influent (S-1), bioreactor effluent (S-2), concentrate (S-3), permeate (S-4), and treated effluent (S-10) streams. A difference in ORP values occurred in the system as influent groundwater went from an oxidizing to a reducing environment during treatment. This resulted in positive values in the influent (S-1), permeate (S-4), and treated effluent (S-10) streams and negative values for the biological effluent (S-2) and concentrate (S-3) streams. Positive values in the influent, permeate, and treated effluent streams are due to an oxygen rich environment in the absence of a microorganism population. Negative values in the bioreactor effluent and concentrate stream are due to microorganisms consuming the oxygen necessary to maintain biological degradation.

Specific Gravity

The specific gravity of the groundwater remained unchanged during the demonstration. The average specific gravities calculated for the influent (S-1), the permeate (S-4), and the treated effluent (S-10) streams were about 1.0. Specific gravity is temperature dependent and will vary with the concentration of total solids in the wastewater.

DO

The average concentration of DO in the groundwater during the demonstration was measured as 3.92 mg/L for the influent (S-1) stream and 3.12 mg/L for the permeate (S-4) stream. Data for the treated effluent (S-10) stream were only sampled during the last month of the demonstration; the average concentration of DO in this stream was determined to be 3.93 mg/L.

Temperature

The average temperature of the groundwater during the demonstration was measured at 24.4° C for the influent (S-1) stream and 33.6° C for the permeate (S-4) stream. The

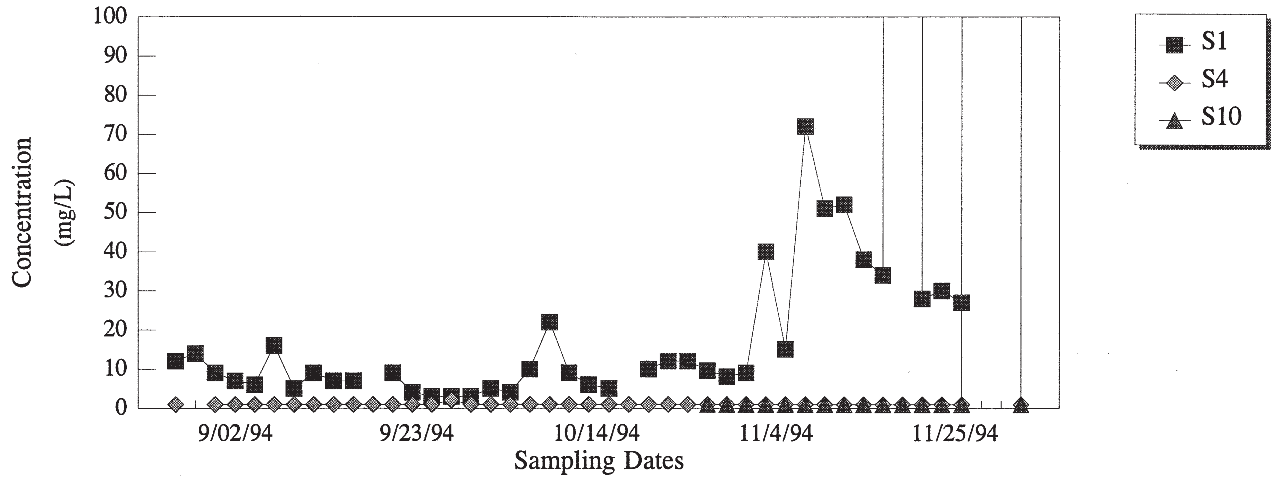


Figure 2-20. VSS concentrations in the S-1, S-4, and S-10 streams. Sample concentrations for S-1 and S-10 significantly exceeded the upper limit scale in November. Values are presented in Table B-13 in Appendix B.

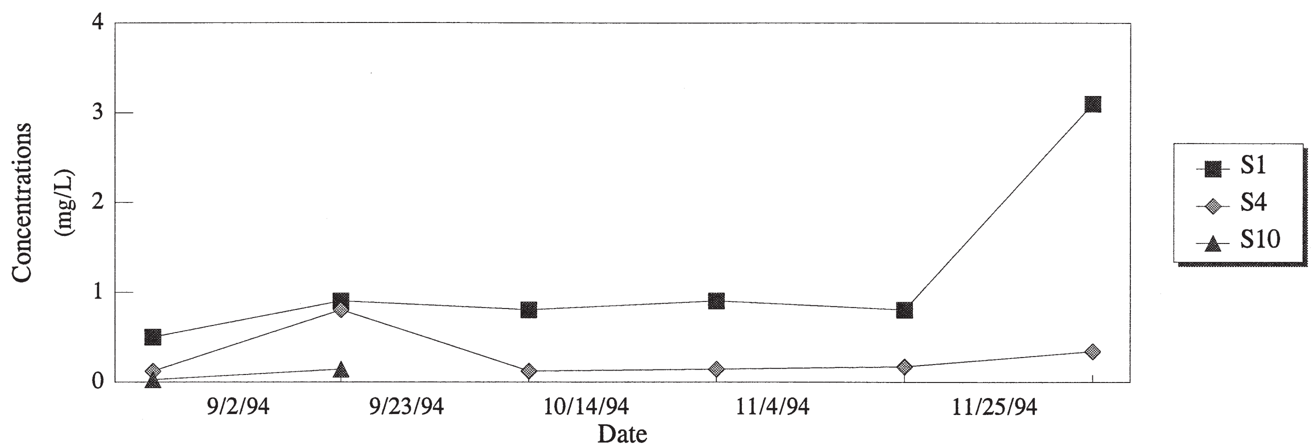


Figure 2-21. TOC concentrations in the S-1, S-4, and S-10 streams.

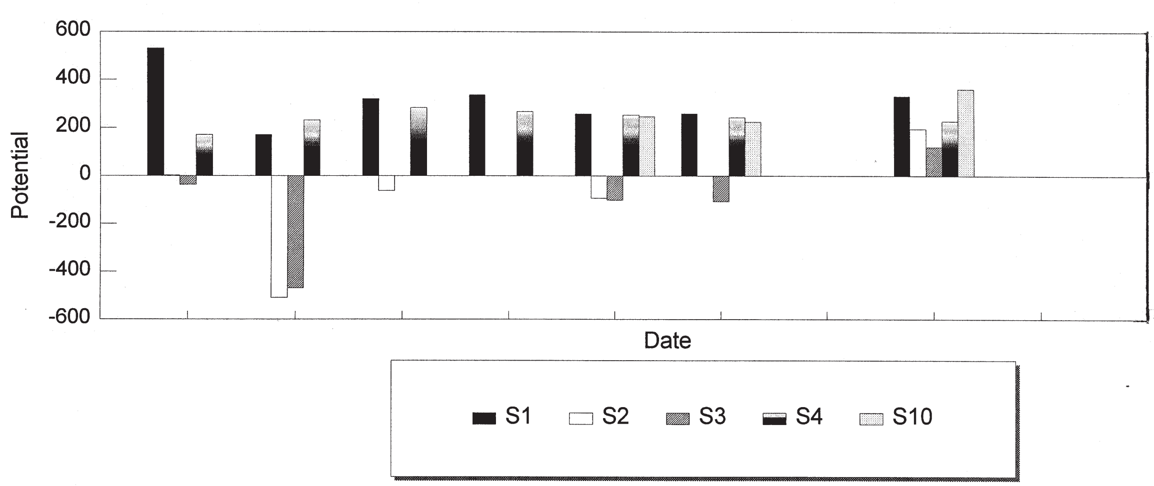


Figure 2-22. ORP in the five streams.

treated effluent (S-10) stream was determined for the last month of the demonstration; the average temperature was 21.1° C. Optimum temperatures for bacterial activity range from 25 to 35° C.

pH

The average pH values in the influent (S-1), the permeate (S-4), and the treated effluent (S-10) streams were measured at 6.3, 7.0, and 7.9, respectively. The treated effluent stream was only measured during the final month of the demonstration. The pH values in the influent (S-1) are adjusted in the bioreactor and the pH values in the permeate (S-4) and treated effluent (S-10) streams are unadjusted values and a function of the biodegradation process.

Nutrients

Concentrations of NO_3^-/NO_2^-, NH_3, PO_4^{-3}, increased slightly in the system. The average concentration of NH_3 increased from 0.13 mg/L in the influent (S-1) stream to 0.34 and 0.59 mg/L for the permeate (S-4) and the treated effluent (S-10) streams, respectively. The treated effluent average was calculated with the exclusion of an anomolous value obtained on November 16.

The average concentration of NO_3^-/NO_2^- increased slightly in the influent (0.48 mg/L) and treated effluent (1.65 mg/L) streams. However, the average value of the NO_3^-/NO_2^- concentration in the S-4 stream, which was less than the detection limit (0.05 mg/L), was below the values collected from the combined S-4 and the S-10 streams. The two values collected for S-10 were 1.6 mg/L, and less than 0.05 mg/L, indicating that the concentration of the sample was below detection limits.

The average concentration of PO_4^{-3} increased throughout the system as shown in the treated, permeate, and treated effluent streams. The average PO_4^{-3} concentration increased from 0.08 mg/L in the influent, to 0.64 mg/L in the permeate, to 0.94 mg/L in the treated effluent.

Section 3
Technology Applications Analysis

This section discusses applicability of the ZenoGem® technology, including the following: applicable waste, factors affecting performance, site characteristics and support requirements, material handling requirements, technology limitations, potential regulatory requirements, and state and community acceptance. The information in this section is based on the results of the SITE demonstration, as well as additional information provided by Zenon and other parties.

3.1 Applicable Waste

Zenon claims that the technology is designed to remove biodegradable organics from wastewater streams, leachates, impoundments, and underground storage tanks. The typical wastewater stream consists of high organic, biological oxygen demand (BOD), and COD concentrations that may contain oils, solvents, surfactants, and detergents. According to Zenon, the feed streams that the technology has successfully treated contained COD concentrations of 50,000 mg/L, BOD concentrations of 6,000 mg/L, suspended solids of 4,000 mg/L, and emulsified grease of 2,500 mg/L. Zenon indicated that the ideal COD to BOD ratio in the wastewater should be 2 to 1. The effluent stream typically has COD concentrations of 500 mg/L, BOD concentrations of 15 mg/L, suspended solid concentrations of 10 mg/L, and emulsified total oil and grease concentrations of 20 mg/L. The waste sludge stream from the system typically contains a total solids concentration of about 30,000 mg/L.

Based on the results of the SITE demonstration, the ZenoGem® technology is capable of reducing concentrations of MMA other TCL VOCs, and COD in contaminated groundwater. Appendix C presents the influent concentrations for MMA (tables C-1 through C-3), COD (tables C-4 through C-6), and VOCs (C-7 through C-9) for the demonstration.

The permeate MMA removal efficiencies consistently surpassed the demonstration goal of 95 percent reduction. The average removal efficiency for MMA was greater than 99.98 ± 0.01 percent for the 3-month demonstration. MMA analyses from the treated effluent stream following the optional permeate carbon filters improved the average removal efficiency of the system to 99.99 ± 0.01 percent. The high removal efficiency for MMA was maintained after a 3-fold concentration was delivered to the system (shock loading test), suggesting that a sudden increase in influent MMA concentration had little noticeable effect on the technology's performance.

The permeate COD reduction efficiencies varied from 84.7 percent to 95.6 percent, yielding an overall COD reduction efficiency of 88.6 ± 8.4 percent. COD analyses from the treated effluent stream following the optional permeate carbon filters improved the average reduction efficiency of the system to 96.8 ± 5.0 percent. The high removal efficiency for COD was maintained after a shock loading test, suggesting that a sudden increase in influent COD concentration had little noticeable effect on the technology's performance.

Due to high MMA concentrations in the influent, the laboratory was unable to analyze aqueous TCL VOC samples at a low enough dilution factor to quantify the low concentrations of TCL VOCs. Therefore, detection limits were low enough in only five of 71 samples collected to quantify TCL VOC concentrations. Consequently, removal efficiencies for individual TCL VOCs could not be calculated for the majority of the samples collected during the demonstration. Reductions of greater than 97 percent were noted in all TCL VOCs reported (methylene chloride, trichloroethene, benzene, toluene, and o+p xylenes).

3.2 Factors Affecting Performance

Based on information provided by the developer, operating parameters that may affect system performance include (1) temperature, (2) pH, (3) inorganic nutrients, and (4) oxygen supply.

Temperature

During the SITE demonstration, Zenon used microorganisms that typically grow best in the temperature range of 20 to 40° C. A high wastewater temperature increases biological activity but rarely causes any severe operating problems. However, the increased metabolic rate during high contaminant loading periods with elevated temperature deplete DO, which may inhibit microorganism growth. A low wastewater temperature can reduce the microbial reaction rate, resulting in a slower degradation. In most cases, temperature changes occur gradually, so modifications in the process operation can be adjusted accordingly.

pH

The hydrogen ion concentration of the groundwater influences microbial growth. Based on SITE demonstration results, the ZenoGem® technology operated best in a neutral or slightly alkaline pH environment. The optimum pH range in the bioreactor is typically maintained between 6.5 and 8.5. Treatment effectiveness does not appear to be affected by changes within this range; however, pH outside of this range can lower treatment performance. For example, based on general microbiology, microbial activity may be inhibited at a pH above 9.0. A pH below 6.5 favors an environment where fungi can overcome microorganisms for food supply. The effects of varying pH, and other geochemical parameters (such as DO and ORP) in the influent groundwater, were not evaluated in detail during the SITE demonstration, as influent groundwater pH was relatively constant throughout the demonstration period.

Inorganic Nutrients

Inorganic nutrients, primarily nitrogen and phosphorus, are essential for the biological process. Insufficient amounts of nutrients will slow the degradation rate of organic compounds. Nitrogen may be provided in a variety of forms, such as nitrate and ammonium salts. Zenon typically performs treatability studies to determine the ideal nutrient requirements for treatment. The ZenoGem® technology typically does not require high nutrient concentrations since the biomass is recycled and retained in the system.

Oxygen

An adequate supply of oxygen is critical to an aerobic environment in which organisms can grow and degrade the organic contaminants. If the supply of oxygen is insufficient, it becomes a limiting factor. Zenon supplies oxygen through air diffusers installed along the bottom of the bioreactor.

3.3 Site-specific Factors Affecting Performance

Site-specific factors can impact the application of the ZenoGem® technology, and these factors should be considered before selecting the technology for remediation of a specific site. Site-specific factors addressed in this section are site area, climate, utilities, maintenance, support systems, and personnel requirements. This section presents support requirements based on information collected during the SITE demonstration.

3.3.1 Site Area

The actual amount of space required for a ZenoGem® system depends on the size of the system used. For the Nascolite demonstration, the pilot-scale system was housed in a transportable trailer. The trailer requires a 12-foot by 60-foot area to support a maximum operating weight of 45,000 pounds. The trailer also requires 14 feet of overhead clearance. About 1,000 square feet are necessary to operate and unload equipment. Once the trailer is set up, the system can be operational within 2 weeks if all necessary utilities, production wells, feed lines, and supplies are available.

According to Zenon, the system can be constructed in a 40-foot internationally accepted container or mounted on a modular skid. The 40-foot container can be modified to provide shelter, where the skid-mounted unit needs to be housed inside a building.

Additional space in a bermed area is required for optional untreated and treated groundwater storage tanks, and a drum staging area for generated wastes. Additionally, a building or shed is useful to protect supplies. Other installation and monitoring requirements include security fencing and access roads for equipment transport.

3.3.2 Climate

The ZenoGem® system is not designed to operate at temperatures near or below freezing. If such temperatures are anticipated, the ZenoGem® full-scale unit and associated storage tanks should be installed in a climate-controlled environment (for example, operating the system in a heated warehouse). In addition, aboveground piping to the system must be protected from freezing.

3.3.3 Utilities

Use of the ZenoGem® system requires water and electricity. Water is required for a safety shower, an eye wash station, personnel decontamination, and bioreactor cooling. For bioreactor cooling, the water supply must be capable of providing 60 psi pressure and a flow rate of 30 gpm. According to Zenon, the cooling water is specific to the trailer mounted unit used for the SITE demonstration and may not be necessary at all sites. Information such as degradation rates, influent COD concentrations, bioreactor size, permeate flow rate, feed flow rate, site location, and general heat balance are some of the factors Zenon considers when determining the need for bioreactor cooling. If water is unavailable, arrangements must be made to deliver, store, and pump water. In addition, about 200 gallons of water are required for equipment washing and decontamination.

Electricity is used to run the pumps and blowers, and to power the computer-controlled operating system. Electricity is required for heating and air conditioning, and running on-site analytical equipment. Electrical power for the ZenoGem® system can be provided by portable generators or 460-volt, 3-phase, 60-Hz, 30-ampere electrical service. Based on observations made during the SITE demonstration and estimates provided by Zenon, the trailer-mounted unit operating for 24 hours draws about 225 kilowatt hours (kWh) of electricity; this extrapolates to annual electrical energy consumption of about 82,000 kWh.

3.3.4 Maintenance

The use of the ultrafiltration module in the system eliminates problems associated with typical wastewater treatment systems that rely on settling characteristics to remove suspended solids from treated effluent. Major problems associated with conventional wastewater treatment processes is sludge bulking, sludge rising, and sludge wasting rate. With the ZenoGem® system, these problems are eliminated with the addition of the ultrafiltration module.

Periodic cleaning of the ultrafiltration membrane may be required when a significant pressure loss (20 percent) is observed in the ultrafiltration module. The cleaning procedure requires filling a 50 gallon clean-in-place tank with clean water, adding a proprietary chemical cleaner, and recirculating the liquid through the membrane and back into the clean-in-place tank. The spent liquid is biodegradable and therefore can be transferred to the bioreactor for treatment.

During operation, it is typical to remove solids (or sludge) from the bioreactor when the TSS are in the range of 25,000 to 30,000 mg/L, or the VSS exceed 25,000 mg/L. Typically, the ZenoGem® system is capable of maintaining a solids retention time of 50 days. The result is extended use of the microorganisms and reduced waste disposal. Solids or sludge are removed by connecting a hose to an outlet port and removing the desired amount of waste from the system.

3.3.5 Support Systems

A piping network from the source of the contaminated groundwater to the ZenoGem® system must be constructed. However, a tanker truck may be used to transport contaminated groundwater to the system. The ZenoGem® system operates in a continuous flow-through mode during remediation. An equalization tank is usually required to contain the groundwater if flow rates to the system are too low.

3.3.6 Personnel Requirements

Once the system is functioning, it generally operates unattended except for periodic monitoring and routine maintenance. An on-site operator (trained by Zenon during the startup phase) should periodically monitor the system to ensure safe, economical, and efficient operation, and to conduct sampling activities. Remote monitoring and alarm systems notify Zenon and the on-site operator of malfunctions in the system. Under normal operating conditions, the operator is required to monitor the system for about 7 hours per week. Time for sampling the influent and effluent, testing the samples for field parameters (temperature, pH, DO, COD, TSS), and packaging and shipping samples off site for TCL VOC analyses is included in this estimate. Zenon performs periodic routine maintenance activities for the treatment equipment.

3.4 Material Handing Requirements

The primary residual generated by the ZenoGem® system is biological waste sludge produced as a by-product of the biological degradation of the waste constituents. The quantity of sludge varies with the type of waste degraded; however, typical values are about 0.1 pound of sludge per pound of COD removed from the influent stream.

Zenon can reduce the volume of waste sludge for disposal by continuously recirculating the contents through the ultrafiltration module. This procedure dewaters and concentrates the sludge, yielding a smaller volume for disposal. During the SITE demonstration, the ultrafiltration module reduced the volume of sludge in the bioreactor from 700 gallons to 400 gallons in about 4 hours. Waste sludge can be stored in 55-gallon drums for off-site transport and disposal. The waste sludge may be subject to Resource Conservation and Recovery Act (RCRA) regulations as a hazardous waste.

Secondary waste streams generated by the ZenoGem® technology consist of proprietary membrane cleaning solution, spent carbon filters, and decontamination water. During the SITE demonstration, Zenon generated about 100 gallons of membrane cleaning solution, which was treated in the bioreactor near the end of the demonstration. Spent carbon used for TCL VOC removal in the permeate and off-gas stream may be disposed of or regenerated. Decontamination water may be stored in 55-gallon drums for off-site disposal. Disposal options depend on local requirements and the presence or absence of contaminants. Disposal options may range from on-site disposal to disposal in a hazardous waste or commercial landfill.

Installation of production wells may be necessary to provide groundwater to the system. During production well drilling, drill cuttings and well development water are generated. During the SITE demonstration, four production wells were drilled to a depth of about 25 feet which produced drill cuttings and development water. The drill cuttings can be stored in 55-gallon drums or in lined, covered, roll-off boxes, or other receptacles. Development water may be stored in 55-gallon drums. Disposal options for this waste depend on local requirements and the presence or absence of contaminants. The options may range from on-site disposal to incineration.

3.5 Technology Limitations

Elevated oil and grease concentrations, inorganic suspended solids, and metals may reduce the treatment efficiency of the system. Elevated oil and grease concentrations can inhibit the growth of microorganisms, resulting in a slower contaminant degradation. Unemulsified oil and grease concentrations may also foul the ultrafiltration membrane surface, reducing the amount of permeate discharge from the module.

Inorganic suspended solids that are not degraded in the bioreactor accumulate in the mixed liquor and may limit the process pumps' efficiency to recirculate the concentrate, and may cause fouling of the ultrafiltration membrane. In addition, metal concentrations can be toxic to microorganisms, reducing biological growth enough to interupt treatment.

Depending on wastewater characteristics, pretreatment can be incorporated into a treatment train to prevent these problems. Pretreatment options include sedimentation, flotation, chemical precipitation, and microfiltration. Zenon manufactures pretreatment systems for any necessary application.

3.6 Potential Regulatory Requirements

This section discusses regulatory requirements pertinent to using the ZenoGem® technology at Superfund, RCRA corrective action, and other cleanup sites. The regulations pertaining to applications of this technology depend on site-specific conditions; therefore, this section presents a general overview of the types of federal regulations that may apply under various conditions. State and local requirements also should be considered; because these requirements vary, however, they are not presented in detail in this section. Table 3-1 summarizes the environmental laws and associated regulations discussed in this section.

Table 3-1. Summary of Environmental Regulations

Act/Authority	Applicability	Application to the ZenoGem® Technology	Citation
CERCLA	Cleanup at Superfund sites	This program authorizes and regulates the cleanup of releases of hazardous substances. It applies to all CERCLA site cleanups and requires consideration of other environmental laws as appropriate to protect human health and the environment.	40 CFR part 300
RCRA	Cleanups at Superfund and RCRA sites	RCRA regulates the transportation, treatment, storage, and disposal of hazardous wastes. RCRA also regulates corrective actions at treatment, storage, and disposal facilities.	40 CFR parts 260 to 270
CWA	Discharges to surface water bodies	NPDES requirements of CWA apply to both Superfund and RCRA sites where treated water is discharged to surface water bodies. Pretreatment standards apply to discharges to POTWs.	40 CFR parts 122 to 125, part 403
SDWA	Water discharges, water reinjection, and sole-source aquifer and wellhead protection	Maximum contaminant concentrations and contaminant concentration goals should be considered when setting water cleanup levels at RCRA corrective action and Superfund sites. Sole sources and protected wellhead water sources would be subject to their respective control programs.	40 CFR parts 141 to 149
CAA	Air emissions from stationary and mobile sources	If VOC emissions occur or hazardous air pollutants are of concern, these standards may be applicable to ensure that use of this technology does not degrade air quality. State air program requirements also should be considered.	40 CFR parts 50, 60, 61, and 70
AEA and RCRA	Mixed waste	AEA and RCRA requirements apply to the treatment, storage, and disposal of mixed waste containing both hazardous and radioactive components. OSWER and DOE directives provide guidance for addressing mixed waste.	AEA (10 CFR part 60) and RCRA (see above)
OSHA	All remedial actions	OSHA regulates on-site construction activities and the health and safety of workers at hazardous waste sites. Installation and operation of the ZenoGem® biological and ultrafiltration process must meet OSHA requirements.	29 CFR parts 1900 to 1926
NRC	All remedial actions	These regulations include radiation protection standards for NRC-licensed activities.	10 CFR part 20

3.6.1 Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by SARA of 1986, authorizes the federal government to respond to releases of hazardous substances, pollutants, or contaminants that may present an imminent and substantial danger to public health or welfare. CERCLA pertains to the ZenoGem® technology by governing the selection and application of remedial technologies at Superfund sites. Remedial alternatives that significantly reduce the volume, toxicity, or mobility of hazardous substances and provide long-term protection are preferred. Selected remedies must be cost-effective, protective of human health and the environment, and must comply with environmental regulations to protect human health and the environment during and after remediation.

CERCLA requires identification and consideration of environmental requirements that are ARARs for site remediation before implementation of a remedial technology at a Superfund site. Subject to specific conditions, EPA allows ARARs to be waived in accordance with Section 121 of CERCLA. The conditions under which an ARAR may be waived are the following: (1) an activity that does not achieve compliance with an ARAR, but is part of a total remedial action that will achieve compliance (such as a removal action); (2) achievement of an equivalent standard of performance without complying with an ARAR; (3) compliance with an ARAR will result in a greater risk to health and the environment than will noncompliance; (4) compliance with an ARAR is technically impracticable; (5) a state ARAR has not been consistently applied; and (6) compliance with the ARAR for fund-lead remedial actions will result in expenditures that are not justifiable in terms of protecting public health or welfare, given the needs for funds at other sites. The justification for a waiver must be clearly demonstrated (EPA 1988a). Off-site remediations are ineligible for ARAR waivers, and all applicable substantive and administrative requirements must be met. CERCLA requires on-site discharges to meet all substantive state and federal ARARs, such as effluent standards. Off-site discharges must comply not only with substantive ARARs, but also state and federal administrative ARARs, such as permitting, designed to facilitate implementation of the substantive requirements.

3.6.2 Resource Conservation and Recovery Act

RCRA, as amended by the Hazardous and Solid Waste Disposal Amendments of 1984, is the primary federal legislation governing management and disposal of hazardous waste. Although a RCRA permit is not required for on-site remedial actions at Superfund sites, the ZenoGem® technology must meet all substantive requirements when treating hazardous wastes.

A RCRA hazardous waste maybe defined as a characteristic or listed waste. Criteria for identifying characteristic hazardous wastes are listed in Title 40 of the Code of Federal Regulations (CFR) Part 261 Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are specified in 40 CFR Part 261 Subpart D. Subtitle C of RCRA contains requirements for generation, transportation, treatment, storage, and disposal of hazardous wastes. Compliance with these requirements is mandatory for CERCLA sites generating, storing, or treating hazardous waste on site.

If the influent groundwater to the technology is classified as hazardous waste, the substantive requirements of a RCRA Subtitle C treatment, storage, and disposal (TSD) permit must be met. If the effluent groundwater is determined to be hazardous and is shipped off site for disposal, a Uniform Hazardous Waste Manifest must accompany the shipment. Air emissions from operation of the ZenoGem[7] system are subject to RCRA regulations on air emissions from hazardous waste TSD operations and are addressed in 40 CFR Part 264 and 265, Subparts AA and BB. The air emission standards are applicable to TSD units subject to the RCRA permitting requirements of 40 CFR part 270 or hazardous waste recycling units that are otherwise subject to the permitting requirements of 40 CFR Part 270.

Transportation of all hazardous material must comply with U.S. Federal Department of Transportation (DOT) hazardous waste packaging, labeling, and transportation regulations. The receiving TSD facility must be permitted or similarity authorized and in compliance with RCRA standards. The RCRA land disposal restrictions (LDR) in 40 CFR 268 preclude the land disposal of hazardous waste that fail to meet stipulated treatment standards. The LDR treatment standards applicable to extracted groundwater, soil cuttings, and residuals from groundwater treatment depend on the process that generated the waste or on the types and concentrations of the contaminants present in these wastes. Wastes that do not meet these standards must receive additional treatment to bring the wastes into compliance with the standards prior to land disposal, or be issued a variance.

3.6.3 Clean Water Act

The Clean Water Act (CWA) is designed to restore and maintain the chemical, physical, and biological quality of navigable surface waters by establishing federal, state, and local discharge standards. Treated effluent water from the ZenoGem® system may be regulated under the CWA if it is discharged to surface water bodies or a POTW. On-site discharges to surface water bodies must meet substantive National Pollution Discharge Elimination System (NPDES) requirements, but do not require a NPDES permit. Off-site discharges to a surface water body require an appropriate NPDES permit and must meet NPDES permit limits. Discharge to a POTW is considered an off-site activity, even if an on-site sewer is used. Therefore, compliance with substantive and administrative requirements of the national pretreatment program is required. General pretreatment regulations are included in 40 CFR Part 403. Any local or state requirements, such as state antidegradation requirements, must be identified and satisfied.

3.6.4 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA), as amended in 1986, requires EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorizes national drinking water standards and a joint federal-state system for ensuring compliance with these standards. The SDWA also regulates underground injection of fluids and sole-source aquifer and well head protection programs.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. SDWA primary or health-based, and secondary or aesthetic maximum contaminant levels (MCL), will generally apply as cleanup standards for water that is, or may be, used for drinking water supply. In some cases, such as when multiple contaminants are present, alternate concentration limits (ACL) may be used. CERCLA and RCRA standards and guidance should be used in establishing ACLs.

If treated effluent water from the ZenoGem® technology is reinjected into the subsurface environment it will be regulated by the underground injection control program found in CFR 40 Parts 144 and 145. Injection wells are categorized as Class I through V, depending on their construction and use. Reinjection of treated water involves Class IV (reinjection) or Class V (recharge) wells and should meet requirements for well construction, operation, and closure. If the groundwater, after treatment, still contains hazardous waste, then its reinjeced into the upper portion of an aquifer would be subject to 40 CFR Part 144.13, which prohibits Class IV wells.

The sole-source aquifer and wellhead protection programs are designed to protect specific drinking water supply sources. If such a source is to be remediated using the ZenoGem® system, appropriate program officials should be notified, and any potential regulatory requirements should be identified. State groundwater antidegradation requirements and water quality standards may also apply.

3.6.5 Clean Air Act

The Clean Air Act (CAA), as amended in 1990, establishes primary and secondary ambient air quality standards for protection of public health and emission limitations for certain hazardous air pollutants. Permitting requirements under CAA are administered by each state as part of State Implementation Plans developed to bring each state into compliance with National Ambient Air Quality Standards (NAAQS).

The ambient air quality standards for specific pollutants apply to the ZenoGem® technology because of emissions from a point source to the ambient air. Allowable emission limits for operating a ZenoGem® system will be established on a case-by-case basis depending on the type of waste treated and whether or not the site is in an attainment area of the NAAQS. Allowable emission limits may be set for specific hazardous air pollutants, particulate matter, or other pollutants. If the site is in an attainment area, the allowable emission limits may still be curtailed by the increments available under Prevention of Significant Deterioration (PSD) regulations. An air abatement device, such as a carbon absorption unit, is typically required to remove VOCs from the process air stream before discharge to the ambient air.

The ARARs pertaining to the CAA can only be determined on a site-by-site basis. Remedial activities involving the ZenoGem® technology may be subject to the requirements of Part C of the CAA for the prevention of significant deterioration of air quality in attainment (or unclassified) areas. The PSD requirements will be applicable when the remedial activities involves a major source or modification as defined in 40 CFR part 2.21. The PSD significant emission rate for VOCs is 40 tons per year. Activities subject to PSD review must ensure application of best available control technologies (BACT) and demonstrate that the activity will not adversely impact ambient air quality.

3.6.6 Mixed Waste Regulations

Use of the ZenoGem® system at sites with radioactive contamination might involve treatment of mixed waste. As defined by the Atomic Energy Act (AEA) and RCRA, mixed waste contains both radioactive and hazardous waste components. Such waste is subject to the requirements of both acts. However, when application of both AEA and RCRA regulations results in a situation that is inconsistent with the AEA (for example, an increased likelihood of radioactive exposure), AEA requirements supersede RCRA requirements (EPA 1988a). OSWER, in conjunction with the Nuclear Regulatory Commission (NRC), has issued several directives to assist in identification, treatment, and disposal of low-level radioactive mixed waste. Various OSWER directives include guidance on defining, identifying, and disposing of commercial, mixed, low-level radioactive, and hazardous waste (EPA 1988b). If the ZenoGem® technology is used to treat groundwater containing low-level mixed waste, these directives should be considered. If high-level mixed waste or transuranic mixed waste is treated, internal Department of Energy (DOE) orders should be considered when developing a protective remedy (DOE 1988). The SDWA and CWA also contain standards for maximum allowable radioactivity levels in water supplies.

3.6.7 Occupational Safety and Health Administration Requirements

The Occupational Safety and Health Administration OSHA requires personnel employed in hazardous waste operations to receive training and comply with specific working procedures while at hazardous waste sites. CERCLA remedial actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective actions sites must be performed in accordance with Part 1926 of OSHA, which provides safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians operating the ZenoGem® system are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum personal protective equipment (PPE) for technicians will include gloves, hard hats, steel-toed boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an 8-hour day.

3.7 State and Community Acceptance

State regulatory agencies will likely be involved in most applications of the ZenoGem® system at hazardous waste sites. Local community agencies and citizens' groups are often actively involved in decisions regarding remedial alternatives.

Because few applications of the ZenoGem® technology have been completed, limited information is available to assess long-term state and community acceptance. However, state and community are generally expected to accept this technology, because (1) the technology does not involve combustion processes, and (2) the system is capable of significantly reducing concentrations of hazardous substances in groundwater.

The New Jersey Department of Environmental Protection (NJDEP) oversees investigation and remedial activities at the Nascolite site. State personnel were actively involved in the preparation of the work plan for the demonstration of the pilot-scale system and monitored system installation and performance. NJDEP will also be actively involved in planning for any full-scale systems installed at the site. The role of states in selecting and applying remedial technologies will likely increase in the future as state environmental agencies increasingly assume many of the oversight and enforcement activities previously performed at the EPA regional level. For these reasons, state regulatory requirements that are sometimes more stringent than federal requirements may take precedence for some applications. As risk-based closure and remediation become more common, site-specific cleanup goals determined by state agencies will drive increasing numbers of remediation projects, including applications involving the ZenoGem® technology.

Section 4
Economic Analysis

This section presents cost estimates for using the ZenoGem® technology to treat groundwater contaminated with VOCs. The cost estimates are based on data compiled during the SITE demonstration at the Nascolite site and information obtained from Zenon, independent vendors, and current environmental restoration cost estimating guidance.

Costs for actual applications of this technology may vary depending on the types and concentrations of the contaminants present, regulatory cleanup requirements, and other site-specific factors. This section presents costs for two hypothetical applications of the ZenoGem® technology to demonstrate how costs may vary between sites with different design and operating requirements.

The cost estimates required a number of assumptions to account for variable site- and waste-related parameters, and to simplify situations that would require complex engineering or financial functions in actual applications. Assumptions regarding the type of system used, flow rate, duration of the remedial project, volume treated, and other factors significantly affect the total estimated cost and cost per gallon of water treated in each scenario.

It is also important to note that the system demonstrated at the Nascolite site was operated at pilot-scale to demonstrate that the system could remove MMA, TCL VOCs, and COD from contaminated groundwater. The cost estimates in this report are partially based on extrapolation of the pilot-scale data to longer periods and higher flow rates. Costs for systems designed for optimal full-scale performance at full capacity may vary significantly from the cost scenarios in this report.

Section 4.1 discusses general factors affecting costs for any application of the ZenoGem® technology; Section 4.2 describes the two scenarios. Section 4.3 summarizes the significant issues and assumptions for the Case 1 analysis, and Section 4.4 discusses the associated costs, Section 4.5 discusses Case 2, and Section 4.6 presents Case 2 costs, Section 4.7 presents conclusions of the economic analyses.

To facilitate comparison with conventional remediation technologies, costs are distributed among 12 categories applicable to typical cleanup activities at Superfund and RCRA sites. These cost categories are (1) site preparation, (2) permitting and regulatory, (3) mobilization and startup, (4) equipment, (5) labor, (6) supplies, (7) utilities, (8) effluent treatment and disposal, (9) residual waste shipping and handling, (10) analytical services, (11) equipment maintenance, and (12) site demobilization (Evans 1990). Costs are rounded to the nearest 100 dollars and considered order-of-magnitude estimates.

4.1 General Factors Affecting Costs

This economic analysis presents estimated costs for two scenarios (Case 1 and Case 2) in which the ZenoGem® system is applied to sites with different characteristics and operating requirements. The selected system must be configured to meet site-specific conditions. These conditions will therefore affect overall costs for any application of the ZenoGem® system by determining operating parameters and implementation costs. It is important to note that the general types of site-specific conditions discussed below will influence costs for virtually any type of groundwater or aqueous waste remediation system.

The regulatory status of the site, which is often determined by the type of waste management activities that occurred on site, the relative risk to nearby populations and ecological receptors, and other factors, affects costs by mandating ARARs and remediation goals. ARARs and remediation goals ultimately determine the type and configuration of the system, operating parameters, duration of the remediation project, effluent management procedures, and other factors affecting costs. Certain types of sites may also have more stringent monitoring requirements than others, depending on regulatory status.

Other site-specific factors affecting costs can generally be divided into waste-related factors and site features. Waste-related factors affecting costs include waste volume, contaminant types and concentrations, and regulatory agency-designated treatment goals.

Waste volume affects total project costs because a larger volume takes longer to remediate or requires a higher treatment system capacity. However, economies of scale can be realized with a larger-volume project because the fixed costs, such as equipment costs, are distributed over the larger volume.

The types and concentrations of contaminants to be treated and the treatment goals for the site determine the appropriate size and configuration of the treatment system components, which affects capital equipment costs. Contaminant concentrations can also influence costs by determining the flow rate at which treatment goals can be met. For example, high concentrations of contaminants or nonaqueous phase liquids (NAPL) may be toxic to the microorganisms in the system at high feed rates, and therefore may require a slower feed rate to the system. The presence of NAPL may also limit the rate at which groundwater may be pumped from an aquifer, and require specialized types of pumps for some applications. Some types of contaminants may create greater oxygen demand in the bioreactor, which may result in higher power consumption and significantly affect electrical costs over a long-term project. Contaminant characteristics will affect sampling requirements and analytical costs, and will determine health and safety procedures and PPE requirements for all site activities. Overall, higher costs will be incurred at sites requiring work at higher health and safety/PPE levels.

Site features affecting costs include site location, accessibility, and infrastructure; hydrogeologic factors; and groundwater chemistry. Site location, accessibility, and infrastructure affect equipment and operating costs, site preparation costs, and mobilization costs. For sites posing a significant risk to nearby potential receptors, remediation goals may be more stringent and require more aggressive treatment programs than situations where a site is relatively isolated from potential receptors. High-visibility sites in densely populated areas may require higher security and the need to minimize obtrusive construction activities, noise, dust, and air emissions. Mobilization and demobilization costs are affected by the relative distances that equipment must travel to the site. Site preparation costs are influenced by the availability of access roads and utility lines and by the need for additional equipment to withstand freezing temperatures in colder climates. In cold climates, the system may need to be housed in a heated structure, and piping may require sub-grade placement or heat tracing to prevent freezing. Within the U.S., there can be significant regional variations in costs for materials and equipment, and utilities.

Assumptions regarding site hydrogeology are critical in determining overall project costs. Hydraulic conductivity and saturated thickness will determine the withdrawal rate necessary to capture or control the migration of a contaminant plume, which affects the rate of flow to (and through) the system and the duration of the remediation project. These factors in turn determine design parameters and costs for the ZenoGem® system and the supporting groundwater extraction and effluent management systems. For example, higher flow rates may require use of a series of filtration modules in parallel and increase the amount of oxygen supplied to the bioreactor. Extraction wells may provide the desired hydraulic control and flow rate in some situations; however, for low-yielding, shallow aquifers, a passive collection system (trench with french drain) may be more effective and economical to construct and operate.

In addition to contaminant characteristics, non-contaminant chemical characteristics of the groundwater or aqueous waste can affect costs in several ways. Groundwater temperature, pH, TSS, DO, and inorganic constituents may impact the metabolic rate within the bioreactor, and determine the need for pretreatment of influent water. High concentrations of suspended solids may foul the filtration membranes. Some soluble metals may be toxic to the organisms in the bioreactor, necessitating additional pretreatment to remove the metals or more frequent sludge disposal. These factors could affect equipment costs, consumable and time-related variable costs, and maintenance costs. Groundwater chemistry may also affect the amount of oxygenation required for feed waste entering the bioreactor, affecting utility costs, and may also influence the management of effluent.

Electricity consumption can vary considerably depending on the total number of pumps and other electrical equipment operating. Treatment systems requiring extraction wells will operate pumps that will incur slightly higher electricity costs depending on the pump sizes. Sites requiring a higher oxygen feed rate for the bioreactor will incur higher electricity costs.

4.2 Overview of Cost Scenarios

Costs were estimated for cases involving two different hypothetical applications of the ZenoGem® system. Case 1 assumes that a rented, trailer-mounted system treats groundwater at a rate of 1,400 gpd for a 1-year period. Case 2 assumes that a modular (skid-mounted) system will be purchased and used to treat leachate at a rate 1,400 gpd for a 10-year period.

Both cases assume a higher flow rate than the 480 gpd rate used during the SITE demonstration. The higher flow rates may be more representative of full-scale applications of the ZenoGem® technology. Based on information provided by Zenon, the higher flow rates are feasible; however, system performance at these higher flow rates was not evaluated during the SITE demonstration. The timeframes assumed for the cost estimates were selected for consistency with cost evaluations of other innovative technologies evaluated by the EPA SITE Program, and because they facilitate comparison to typical costs associated with conventional, remedial options. However, neither timeframe reflects estimates of the time that may actually be required to remediate groundwater at the Nascolite site.

Case 1 is based on a system similar to the trailer-mounted system used during the SITE demonstration, operating for a relatively short operating period. Renting Zenon's mobile, trailer-mounted system may be especially applicable for short-term, aggressive remedial programs where rapid mobilization and startup with minimal site preparation are desired. For example, the trailer-mounted system could be rapidly deployed and set up at a spill site when a nearby water supply source is threatened. Depending on the magnitude of the problem, the system could either be part of the permanent remedial solution, or an interim measure associated with a containment program while the scope of the problem and a permanent solution are determined. The short operating period limits the total volume of groundwater potentially treated in Case 1, resulting in a higher estimated cost per gallon of water treated than in Case 2. However, short-term treatment costs per gallon would be comparatively high (relative to long-term costs) for many types of groundwater treatment systems. In emergency response situations, technical feasibility, proven reliability, and speed of deployment are often primary considerations.

In Case 2, the ZenoGem® technology is used for a long-term project to treat landfill leachate containing VOCs and high BOD. The primary goal of the remedial project in Case 2 is containment and treatment of leachate as it is generated, rather than a situation such as Case 1, where an aquifer is already contaminated and a more aggressive remedial program is necessary. For this reason, timeframe for deployment is not assumed to be as critical as in Case 1. Case 2 assumes that time for more extensive site support facilities (such as a building to house the less-expensive, skid-mounted system) to be constructed. The system operates for a 10-year period, and treats a much larger volume than the system in Case 1. Although total costs are higher than in Case 1, the estimated cost per gallon is significantly lower because all costs are distributed over a larger treatment volume.

4.3 Case 1 Analysis

Case 1 is presented to demonstrate application of the ZenoGem® system to a short-term groundwater remediation project requiring a mobile system capable of rapid deployment with minimal site preparation. Section 4.3.1 presents the key issues and assumptions considered for the Case 1 cost estimate; Section 4.3.2 discusses waste characteristics and site features; and Section 4.3.3 presents equipment and operating parameters.

4.3.1 Issues and Assumptions

This section summarizes major issues and assumptions regarding site-specific factors and equipment and operating parameters for Case 1. In general, ZenoGem® equipment operating assumptions are based on information provided by Zenon and observations made during the SITE demonstration. Other assumptions are based on current engineering cost guidance.

4.3.2 Waste Characteristics and Site Features

Assumptions regarding waste characteristics and site features are the following:

- The site is a Superfund site; site hydrogeology and contaminant characteristics are well-characterized.

- The system will be used as an interim, short-term containment measure to limit off-site migration of a small contaminant plume while a permanent remedial solution is being selected. The project requires removal and treatment of about 500,000 gallons of groundwater over a 1 year period.

- The influent stream is groundwater contaminated with MMA at an average concentration of 3,000 mg/L.

- All contamination is in dissolved phase (no NAPL is present).

- Level D (minimal) or E (no specific requirements) health and safety/PPE requirements will apply to all site activities.

- No pretreatment is required.

- Contaminated groundwater will be extracted from a moderate-yielding sand and gravel aquifer. The top of the sand and gravel zone is about 5 feet bgs. The depth to water is about 15 feet bgs, and the base of the aquifer is about 25 feet bgs.

- The groundwater plume is relatively small; one extraction well will provide the desired feed rate to the system (1,440 gpd total or about 1 gpm).

- No sewer lines exist on site, and no POTWs are located in the area. Because contaminants will be treated to nondetectable levels, effluent groundwater can be returned to the aquifer through an injection well located adjacent to the treatment system, upgradient from the extraction well.

- The site is located in a rural area in the northeastern U.S. Regional winter temperatures are below 0° C for several days in a row, requiring antifreezing measures.

- The site is located in a rural area, but has existing electrical lines, access roads, and a security fence.

- The ZenoGem® system is mobilized from within 500 miles of the site.

4.3.3 Equipment and Operating Parameters

Some assumptions regarding the equipment for Case 1 are based on SITE demonstration data for the system demonstrated at the Nascolite site, extrapolated to a 1-year operating period. Different operating parameters (most significantly flow rate) were assumed to more closely approximate operating conditions for full-scale applications.

Assumptions regarding equipment and operating parameters for Case 1 are the following:

- The ZenoGem® treatment system is mounted in a mobile, 46-foot, refrigerated and heated semitrailer.

- The system will be rented for a period of 1 year. Depreciation and salvage value is assumed to be incurred by Zenon and reflected in the rental costs.

- The system is mobilized to the site and assembled by Zenon. Zenon will also perform periodic maintenance and modification activities paid by the client.

- Groundwater will be treated to meet MCLs.

- The treatment system is operated 24 hours per day, 7 days per week, for 1 year. Downtime for routine maintenance is assumed to be minimal and is not considered in this estimate.

- The system operates at a flow rate of 1,440 gpd, treating a total of 530,000 gallons during the year.

- System effluent will require carbon polishing to achieve nondetectable target cleanup goals. Air emissions will also be cleaned by carbon prior to release to the atmosphere; air discharge permits and air sampling are assumed to not be required.

- The treatment system operates automatically without the constant attention of an operator and will shut down in the event of system malfunction.

- One technician will be needed part time to inspect the equipment, collect weekly samples, and conduct routine maintenance on the system. Initial operator training is provided by Zenon.

- Sampling and analytical QA/QC requirements for system performance monitoring will not be as stringent as those followed during the SITE demonstration. One treated and one untreated aqueous sample will be collected weekly and analyzed by an off-site laboratory for VOCs. Treated and untreated aqueous samples will also be collected periodically and analyzed on site for temperature, pH, COD, and DO to monitor system performance.

4.4 Case 1 Costs

This section presents the costs associated with Case 1. Subsections are organized to correspond with the 12 cost categories typical to Superfund sites. Table 4-1 shows a breakdown of the Case 1 costs by category, and Figure 4-1 shows the cost percentage distribution for each category.

4.4.1 Site Preparation Costs

Site preparation costs include a treatability study, administrative costs, treatment area preparation, and design costs. For this analysis, administrative costs, such as costs for legal searches, access rights, and site planning activities, are estimated to be minimal as the system will be deployed rapidly and set up at a site that has been extensively investigated. Total administrative costs are assumed to be about $10,000.

Zenon will conduct a treatability study to determine if the ZenoGem® technology is suitable for remediation, and to determine the design specifications for the site. Zenon estimates a typical treatability study to cost about $5,000, including labor and equipment costs.

Treatment area preparation includes constructing an extraction well, installing the pump, valves, and piping to carry the groundwater to the ZenoGem® treatment system, and constructing an injection well for returning treated water to the aquifer. This analysis assumes that one 25-foot-deep, 4-inch-diameter extraction well will be needed, and that the well can be installed using hollow-stem auger drilling methods. The well can be drilled, constructed, and developed for about $70 per foot plus maximum drill rig mobilization costs of $1,000 (assuming driller mobilization from within 100 miles of the site) for a total estimated cost of about $2,900. Alternatively, if groundwater monitoring wells already exist in the plume area, it is possible that they may modified to serve as extraction wells (provided the yield is sufficient), eliminating the need to construct a new extraction well.

A submersible pump will maintain the flow rate necessary for this case. The estimated pump cost, including electrical controls and installation, is about $3,000. Insulated, heat-traced piping and valve connection costs are estimated to be about $25.00 per foot for a total cost of $5,000, assuming the well will be located less than 200 feet from the treatment system. The total costs for pumps and piping are estimated to be about $8,000.

The system will require continuous management of the treated groundwater. If groundwater monitoring wells exist in the treatment area, they may be modified to serve as injection wells, and construction of a groundwater recharge system may not be required. This cost analysis assumes that construction of an injection well will be required. The ZenoGem® treatment system will be located upgradient from the extraction well in this case. For this reason, the injection well could be located adjacent to the treatment system, allowing injected, treated water to continuously recirculate through the contaminated zone. An injection well would have the same general design specifications as the extraction well, with the exception that no pump would be required, and could be installed at the same time as the extraction well, without requiring a separate mobilization. The cost for this well is estimated to be $1,500.

Design costs include engineering designs for extraction and injection well placement and construction, electrical power supply and piping configurations, site layout, and any other necessary engineering services. Case 1 assumes that site hydrogeology and contaminant characteristics have been defined through RI/FS activities, so the extraction and injection well designs will require minimal effort. Treatment equipment design is included in this calculation to account for any design modifications Zenon may make prior to mobilizing the system. However, because the rented, mobile system will be used, treatment equipment design will generally be limited to determining optimal operating parameters based on the results of the treatability study. For these reasons, design costs for Case 1 are assumed to be minimal. Design costs are estimated to be about 10 percent of the combined costs of construction (described above) and first-month rental of the treatment system. Based on these assumptions, total design costs are estimated to be about $2,500.

Total site preparation costs for this case are estimated to be about $29,900.

Table 4-1. Costs Associated with the ZenoGem® Technology - Case 1

	Cost Categories	Itemized Costs	Total Cost
FIXED COSTS:	**Site Preparation Costs:**		$29,500
	Administrative	$10,000	
	Extraction and Injection Wells	4,000	
	Pump and Piping	8,000	
	Treatability Study	5,000	
	Design Costs	2,500	
	Permitting and Regulatory Costs		5,000
	Mobilization and Startup Costs:		6,400
	Treatment Equipment	1,400	
	Labor	2,800	
	Utility Connection	2,200	
	Site Demobilization Costs:		5,100
	Disassembly and	1,700	
	Treatment Equipment	1,400	
	Site Restoration	2000	
	Total Estimated Fixed Costs		$46,000
VARIABLE:	**Equipment Costs:**		$166,200
	Treatment Equipment	159,200	
	Monitoring Equipment	7,000	
	Labor Costs (routine operating labor)		12,700
	Supply Costs:		6,800
	Chemical Additives	300	
	Carbon Columns	6,000	
	PPE	200	
	Sampling Supplies	300	
	Utility Costs (electricity)		7,400
	Residual Waste Treatment and		4,200
	Analytical Services Costs		10,100
	Equipment Maintenance Costs:		10,000
	Equipment	4,800	
	Maintenance Labor	5,200	
	Total Variable Costs		$217,400
TOTAL ESTIMATED FIXED AND VARIABLE COSTS[a]			**$263,400**
Total cost per gallon treated[b]			**$0.50**

Notes:

[a] Total over a 1-year period.

[b] Total of 530,000 gallons treated.

4.4.2 Permitting and Regulatory Costs

Remedial actions at Superfund sites must be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. In general, permitting and regulatory costs are highly variable as ARARs must be determined on a site-specific basis. Remediation at RCRA corrective action sites requires additional monitoring and recordkeeping, which can increase regulatory costs. Sites requiring permits for effluent discharge to sewers or surface water bodies may incur significant permitting fees and associated administrative costs.

For estimating purposes, permitting and regulatory costs for Case 1 are assumed to be minimal since the primary goal is rapid mobilization and protection of a public water supply. Permitting costs would primarily be related to obtaining permits or waivers to allow reinjection of treated water, and are estimated to be $5,000. No air discharge permits are assumed to be required.

4.4.3 Mobilization and Startup Costs

Mobilization and startup costs include the costs for transporting the ZenoGem® system and auxiliary equipment to the site, assembly and shakedown of the system, electrical power supply hookup, and connection to the piping systems.

Transportation costs are site-specific and vary depending on distance between the site and the point of mobilization. For this analysis, the ZenoGem® equipment is assumed to be transported 500 miles. A cartage company will be retained to transport the trailer-mounted treatment system. Mobilization and transport costs are about $2.80 per mile, for a total cost of $1,400. No oversized vehicle highway permits are assumed to be needed.

Assembly costs include the costs of securing the trailer, assembling the ZenoGem® system, and connecting extraction well piping, and hooking up electrical lines. Zenon provides trained personnel to assemble and shakedown the ZenoGem® system. Zenon personnel are assumed to be trained in hazardous waste site health and safety procedures, so health and safety training costs are not included as a direct startup cost. A two-person crew charged at $70 per hour will work five 8-hour days to assemble the system and perform the initial shakedown. Electrical connecting costs are assumed to be about $2,200. The total assembly costs are about $5,000, including labor and connection costs.

Zenon personnel will also train an on-site operator to perform routine system monitoring necessary to ensure optimal performance. The monthly equipment rental costs include the cost of this training, so no additional training costs are incurred.

Total mobilization and startup costs for Case 1 are estimated to be $6,400.

4.4.4 Equipment Costs

Equipment costs include the costs of renting the ZenoGem® treatment system, auxiliary equipment, and monitoring equipment. For Case 1, Zenon will provide a trailer-mounted system that includes the following major components: an influent holding-equalization tank, a bioreactor, an ultrafiltration module, an air blower, a pH buffer tank, a nutrient solution tank, off-gas carbon filters, permeate carbon filters, and feed, process, and metering pumps. Zenon will rent the trailer-mounted system for $13,300 per month. For a 1-year term, the total ZenoGem® system rental costs will be $159,200.

Monitoring equipment includes a pH meter, spectrophotometer, and other miscellaneous analytical equipment. The assumed cost for renting this equipment is $7,000 for the remedial effort.

Total equipment costs for Case 1 are $166,200.

4.4.5 Labor Costs (Routine Operating Labor)

Once the system is functioning, it will generally operate unattended except for periodic monitoring and routine maintenance. An on-site operator (trained by Zenon during the startup phase) should periodically monitor the system to ensure safe, economical, and efficient operation, and to conduct sampling activities. Remote monitoring and alarm systems notify Zenon and the on-site operator of malfunctions in the system. Under normal operating conditions, the operator is required to monitor the system for about 7 hours per week. Time for sampling the influent and effluent, testing the samples for field parameters (temperature, pH, DO, COD, TSS), and packaging and shipping samples for off-site VOC analysis is included in this estimate. Assuming a labor charge of $35 per hour, total labor costs are estimated to be $12,700 over a 1-year period.

Zenon performs periodic routine maintenance activities for the treatment equipment. These activities and associated costs are discussed in Section 4.4.11, Equipment Maintenance Costs.

4.4.6 Supply Costs

Supplies required for this analysis of the ZenoGem® treatment system include standard operating supplies such as treatment chemicals, carbon columns, disposable personal protective equipment (PPE), and sampling supplies. Treatment chemicals include MC-1 cleaner (to clean the ultrafiltration membranes), available at $6.89 per kilogram (kg), and phosphorous nutrient available for $0.25 per kg. Based on observations made during the SITE demonstration, about 24 kilogram of MC-1 cleaner and 465 kilogram of phosphorous nutrient will be required to treat 530,000 gallons of water. Total treatment chemical costs are estimated at $300.

The system may require carbon adsorption for final polishing of treated effluent to achieve nondetectable contaminant concentrations, and for treating off-gases. The number of carbon columns required is highly site-specific and will depend on the flow rate, influent contaminant concentrations, and other factors. Based on the results of the SITE demonstration extrapolated to a 1-year period and a higher flow rate, this estimate assumes that effluent polishing will require two carbon columns that will need be replaced every 3 months. Off-gas treatment will require two additional columns that will require replacement every 6 months. Based on these assumptions, a total of 12 carbon columns will be used during the 1 year-long project. Assuming replacement columns cost about $500 each, total carbon column costs are about $6,000.

Supply costs also include costs for Level D disposable PPE and other sampling supplies. Disposable PPE typically consists of Tyvek™ suits, latex inner gloves, nitrile outer gloves, and safety glasses. Disposable PPE for this case is assumed to cost about $200 for the 1-year period. Other sampling supplies consist of sample bottles and shipping containers. For routine monitoring, laboratory glassware is also needed. The numbers and types of sampling supplies needed are based on the analyses to be performed. For this case, sampling supply costs are assumed to be about $300 for the 1-year period.

Total supply costs for Case 1 are estimated to be $6,800.

4.4.7 Utility Costs

Electricity is the only utility used by the ZenoGem® system. Electricity is used to run the pumps and blowers of the treatment system, and to power the computer-controlled operating system, heating and air conditioning, and on-site analytical equipment. Electricity costs may vary considerably depending on the geographic location of the site and local utility rates. Costs for connection to existing electrical lines were included under "Site Preparation."

Based on observations during the SITE demonstration and estimates provided by Zenon, the trailer-mounted system operating for 24 hours draws about 225 kWh of electricity; this extrapolates to annual electrical energy consumption 82,125 kWh. Electricity is assumed to cost $0.09 per kWh, including demand and usage charges, resulting in total estimated electricity costs of about $7,400.

4.4.8 Effluent Treatment and Disposal Costs

Cleanup goals are assumed to be MCLs. Monitoring is routinely conducted by the operator to ensure that effluent meets MCL criteria before exiting the system (see Section 4.4.10). As a result, the effluent can be returned to the aquifer through an infiltration gallery. Costs for constructing the infiltration gallery were presented in Section 4.4.1, Site Preparation Costs. The ZenoGem® system produces air emissions that pass through a carbon column prior to release to the atmosphere, and carbon adsorption is used to polish the effluent water before discharge. The costs for the carbon columns were presented in Section 4.4.6. For these reasons, this estimate assumes no additional costs will be incurred for the treatment or disposal of the effluent.

4.4.9 Residual Waste Shipping and Handling Costs

The only residual waste directly produced by the ZenoGem® process is a waste sludge, which consists of microorganisms and unfiltered wastewater from the bioreactor. The sludge generation rate is highly site-specific; for this reason, costs for residual waste disposal may vary significantly from estimates presented in this document. The volume of sludge can be reduced by continuously recirculating it through the ultrafiltration module. This procedure which partially dewaters the sludge, reduced the total sludge volume by about 40 percent during the SITE demonstration. This dewatered material is assumed to be a hazardous waste and must be managed in accordance with applicable regulations. For this analysis, Zenon estimates that about 3.6 wet tons (about twelve 55-gallon drums) of sludge will require disposal after the groundwater remediation project has concluded. Case 1 assumes that this material can be removed, transported, and disposed of for about $400 per ton, resulting in a cost of about $1,400.

Peripheral treatment systems may generate residual wastes. For this cost estimate, carbon polishing of the effluent and air emissions is assumed to generate about 12 spent carbon canisters over the course of the project. These canisters require management as potentially hazardous wastes. Off-site transport and disposal costs for the spent carbon canisters are assumed to be about $175 per canister, resulting in a total disposal cost of $2,800 for the 1-year project. Total costs for disposal of spent carbon will be highly site-specific, depending on the amount of carbon required to achieve target cleanup levels.

Total residual waste management costs for Case 1 are assumed to be about $4,200.

4.4.10 Analytical Services Costs

Sampling frequency and number of samples are site-specific and will depend on treatment goals, contaminant concentrations, and ARARs of applicable federal, state, and local regulations. This analysis assumes that weekly samples of untreated water and treated effluent will be analyzed at an off-site laboratory for VOCs by Method 8240 at a cost of $195 per sample. Case 1 assumes that standard laboratory batch QA/QC samples (laboratory blanks, trip blanks, blank spike, and matrix spike/matrix spike duplicate [MS/MSD] samples) will be analyzed at no additional cost, and therefore no additional QC sample analytical costs will be incurred. (Cases requiring site-specific, field-prepared MS/MSD, field duplicate, and blank samples will incur higher analytical costs. Also - this cost estimate includes only those samples required for system performance monitoring. Additional groundwater samples may be required to monitor the overall effectiveness of the remedial program, resulting in additional costs.) Additional on-site analyses (temperature, pH, DO, COD, and TSS) are performed using in-line or field instrumentation, and incur no additional costs other than labor and equipment rental, which were addressed in other sections. Based on these assumptions, the analytical costs over a 1-year period are about $10,100.

4.4.11 Equipment Maintenance Costs

Zenon will provide periodic routine equipment maintenance. Annual equipment maintenance costs, excluding labor, are estimated to be about 3 percent of the capital equipment costs, for a total of $4,800. Routine maintenance labor requires about 1 hour per week, and occasional backflushing maintenance labor requires about 1 day per month. This results in a total of 148 labor hours per year. Billed at $35 per hour, maintenance labor costs are about $5,200. Total equipment maintenance costs for Case 1 are estimated to be about $10,000.

4.4.12 Site Demobilization Costs

Site demobilization includes treatment system shutdown, disassembly, and decontamination; transportation of the ZenoGem® equipment and auxiliary equipment off site; and site cleanup and restoration. A two-person crew earning a total of $70 per hour will work about three 8-hour days to disassemble and decontaminate the system. This labor will cost about $1,700. This analysis assumes that the ZenoGem® equipment will be transported 500 miles at $2.80 per mile for a total cost of $1,400.

Site cleanup and restoration involves decommissioning piping and the treatment gallery and optional grading and reseeding of the treatment area. The extraction well and the injection well will be left in place for possible incorporation into long-term monitoring or remediation programs. The piping between the extraction well and the treatment system will be decontaminated before the treatment system is shut down, and will then be removed and disposed of as nonhazardous material or scrap. Minimal regrading and reseeding will be required, as no permanent concrete pads or structures were used. Total site restoration costs are estimated to be about $2,000.

The total assumed cost of demobilization is about $5,100 for Case 1.

4.5 Case 2 Analysis

For Case 2 analysis, the ZenoGem® treatment system is modular and semipermanent. The system is used to treat landfill leachate and will be operated for 10 years. Case 2 is presented in order to analyze a purchased system operating as a long-term wastewater treatment facility.

4.5.1 Issues and Assumptions

This section summarizes major issues and assumptions for Case 2. Due to the long-term nature of the project, Case 2 required several assumptions to simplify the cost estimate, consisting of (1) unit variable costs will remain constant for the 10-year life of the project; (2) costs are not adjusted for inflation; and (3) depreciation and salvage value were not included in the cost estimates and do not appear to significantly affect the overall cost per gallon in this case. In general, ZenoGem® equipment operating issues and assumptions are based on information provided by Zenon and observations made during the SITE demonstration.

4.5.2 Waste Characteristics and Site Features

Significant assumptions for site-specific conditions in Case 2 are the following:

- The site is a Superfund site located in the northeastern U.S.
- The site is a landfill that generates approximately 1,440 gallons of leachate per day.
- A functioning leachate collection system and sump exist on site; however, no functioning leachate treatment system exists on site.
- Contaminants in the leachate can be degraded using the ZenoGem® process but will not be toxic to the organisms in the bioreactor. Contaminants include total VOC concentrations of 5,000 mg/L, and COD of 7,000 mg/L. Contaminant characteristics remain constant over the life of the project.
- Health and safety/PPE Level D (minimal) or E (no specific requirements) criteria will apply to all site activities.
- The leachate has an initial pH ranging from 8 to 10 that needs to be adjusted to 7.5 during treatment.
- No other pretreatment, such as oil separation or solids removal, is necessary.
- The total volume of leachate to treat is nearly 5.3 million gallons. This volume corresponds to the volume treated by the modular unit operating continuously for 10 years at a flow rate of 1,440 gpd.
- The site is located in a rural area.
- Infrastructure existing on or adjacent to the site consists of electricity lines, access roads, sanitary sewer lines, water lines, and a security fence.
- The ZenoGem® system is mobilized to the site from within 500 miles of the site in two semitrailers.

4.5.3 Equipment and Operating Parameters

Assumptions regarding equipment and operating parameters for Case 2 are the following:

- The treatment system is operated on a continuous flow cycle 365 days per year for a period of 10 years.
- The treatment system operates at a flow rate of 1 gpm for a total of about 1,440 gpd or 530,000 gallons per year.
- The treatment system operates automatically without the constant attention of an operator and will shut down in the event of system malfunction.
- One technician will be needed part time to inspect the equipment, collect weekly samples, and conduct routine maintenance on the system.
- Zenon performs additional maintenance and modification activities paid by the customer.
- Initial operator training is provided by Zenon.
- Sampling requirements include monthly influent and effluent samples, analyzed at an off-site laboratory for VOCs, COD, BOD, TOC and metals. DO, pH, and TSS will be monitored daily through on-site sample analysis or in-line instrumentation.

- The system is mobilized to the site and assembled by Zenon.
- Air emissions will pass through carbon prior to discharge to the atmosphere; air discharge permits and air sampling are not assumed to be required
- Leachate will be treated and discharged to a sanitary sewer for eventual treatment at a local POTW.

4.6 Case 2 Costs

This section discusses costs associated with Case 2. The subsections below are organized by the same 12 general cost categories used in the Case 1 analysis, and correspond with the 12 general categories in Table 4-2, which summarizes the cost data.

4.6.1 Site Preparation Costs

Site preparation costs include administrative, permitting, treatment area preparation, and design costs. For Case 2, administrative costs will be higher than Case 1 due to the longer remedial period and scale of the project, more extensive construction activities, higher contaminant concentrations, the need for off-site management of treated effluent, and setting up standard operating procedures for long-term activities (for example, O&M, sampling, and recordkeeping). For this reason, administrative costs related to site preparation for Case 2 are assumed to be $20,000. (Long-term recordkeeping costs are discussed in Section 4.6.5, "Labor Costs.")

Treatment area preparation includes constructing a concrete pad and shelter for the unit. It also includes a leachate collection system, installing piping, a flow meter, and a sewer box for disposal of treated effluent, as well as electrical connections.

The skid-mounted system is not housed in a protective enclosure, so a building with a concrete floor must be constructed. The building must be large enough to house the complete system, including the bioreactor, and should have additional space for storage of treatment chemicals, sampling equipment, and other items. The building should be temperature-controlled, and have potable water and electricity available. This estimate assumes that a 500-square-foot, prefabricated metal building, equipped with a heating, ventilation, and air conditioning system, electrical power and water supply, could be constructed on site for $50 per square foot, not including the concrete pad. The concrete pad consists of a 500-square-foot, 6-inch-thick pad sealed with an epoxy coating, and equipped with berms and sumps to contain potentially hazardous spills. An unreinforced concrete pad can be built for $25 per square foot. Based on these unit costs, total cost for the building and concrete slab is estimated to be $37,500.

State and federal hazardous waste regulations typically require leachate management systems, where applicable, for landfills constructed after 1980. Because this cost estimate assumes that the landfill is relatively new, a functioning leachate collection system is assumed to already be present on site. (Costs for leachate collection systems are highly site-specific and can vary by several orders of magnitude, depending on the size and depth of the landfill, volume and characteristics of the leachate to be managed, applicable regulations, and other factors.) The system is assumed to consist of a subgrade french drain and a 2,000-gallon collection sump with a pump and float-level control at the downstream end. In this case, the treatment system will be located near the collection sump, so minimal additional piping (100 feet) is required to transfer the leachate to the ZenoGem® system. Costs for piping and configuring the connection to the indoor treatment system are assumed to be $5,000.

The system will operate continuously, requiring continuous management of treated effluent. This cost estimate assumes that injection of the treated effluent is practical because the feed waste did not originate in an aquifer. Assuming the effluent will meet criteria for treatment at a local POTW, discharge to a local sewer system may prove to be practical and economical if existing sewer lines and a POTW are nearby. If a sewer line does not exist near the site, the effluent may be stored and transported to a POTW in tankers; however, over a long-term project, this method of effluent management would incur higher costs. This estimate assumes that the area near the landfill is serviced by a municipal sanitary sewer line, and that the line is within 200 feet of the treatment system, and the local POTW accepts industrial wastewater into the system. Combined costs for constructing piping from the system to the sewer line, constructing a junction box with a manhole and flow meter, and connecting the effluent line to the sewer line, are estimated to be about $10,000. The local sewer district may also require a one-time sewer connection fee, which is included under "Permitting and Regulatory Costs" (Section 4.6.2).

Table 4-2. Costs Associated with the ZenoGem® Technology - Case 2

	Cost Categories	Itemized Costs	Total Cost
FIXED COSTS:	**Site Preparation Costs:**		$98,900
	Administrative	$20,000	
	Building and Concrete Pad	37,500	
	Connect to Existing Leachate	5,000	
	Effluent Connection to Sewer	10,000	
	Treatability Study	7,500	
	Design Costs	18,900	
	Permitting and Regulatory Costs		12,900
	Equipment Costs:		148,300
	Treatment Equipment	136,000	
	Auxiliary Equipment	5,300	
	Monitoring Equipment	7,000	
	Mobilization and Startup Costs:		9,800
	Treatment Equipment	2,800	
	Labor	3,900	
	Utility Connections	3,100	
	Site Demobilization Costs		1,700
	Total Estimated Fixed Costs		$271,600
VARIABLE:	**Labor Costs** (Operating, Admin., and		$17,100
	Supply Costs:		5,400
	Replacement Membranes	800	
	Treatment Chemicals	2,100	
	Carbon Columns	2,000	
	PPE	200	
	Sampling Supplies	300	
	Utility Costs (electricity)		28,000
	Effluent Treatment and Disposal		1,600
	Residual Waste Treatment and		12,700
	Analytical Services Costs		14,300
	Equipment Maintenance Costs:		9,300
	Equipment	4,100	
	Maintenance Labor	5,200	
	Total Annual Variable Costs		$88,400
TOTAL ESTIMATED FIXED AND VARIABLE COSTS[a]			**$1,155,600**
Total Cost per gallon treated[b]			**$0.22**

Notes:

[a] Total over a 10-year period.

[b] Total of 5,300,000 gallons treated.

As in Case 1, Zenon will conduct a treatability study before determining the appropriate design specifications. However, for Case 2, the nature of the feed waste is more complex than Case 1. For this reason, the treatability study is assumed to cost $7,500, including labor and equipment costs.

Design costs include engineering designs for overall site layout, building and concrete pad specifications, effluent management system, and any other necessary engineering services. Treatment equipment design is also included in this calculation to account for design modifications Zenon may make prior to mobilizing the system. Total design costs for Case 2 are estimated to be 10 percent of the combined treatment area construction costs (described above) and treatment equipment costs. Total design costs are estimated to be about $18,900.

Total site preparation costs for this case are estimated to be $98,900.

4.6.2 Permitting and Regulatory Costs

Assumed site-specific factors that result in higher permitting costs for Case 2 include more extensive construction activities and the need for obtaining discharge permits for treated effluent. For Case 2, permitting costs are estimated to be 8 percent of the capital equipment costs (about $10,900), plus a $2,000 sewer connection fee, for a total of $12,900.

4.6.3 Mobilization and Startup Costs

Mobilization and startup costs include the costs of transporting the ZenoGem® treatment equipment to the site, assembling the system, connecting up to the leachate collection and effluent management systems and electricity.

For Case 2, the ZenoGem® equipment is assumed to be transported 500 miles. A cartage company will be retained to transport the equipment in two semitrailers. Mobilization costs are about $2.80 per mile for each trailer, for a total cost of $2,800. No oversized vehicle highway permits are assumed to be needed.

As in Case 1, Zenon will provide health- and safety-trained personnel to unload the equipment, assemble the ZenoGem® system, connect piping and electricity, and shake down the system. A two-person crew charged at a total of $70 per hour will work seven 8-hour days to assemble the system and perform the initial shakedown. The total assembly costs are assumed to be about $7,000, including labor and connection costs.

Total mobilization and startup costs for Case 2 are estimated to be $9,800.

4.6.4 Equipment Costs

Equipment costs include the costs of purchasing the ZenoGem® treatment system, auxiliary equipment, and monitoring equipment. According to Zenon, the skid-mounted treatment system configured for a 1,440 gpd flow rate will cost $136,000.

Auxiliary equipment includes a 6,000-gallon reserve holding tank. This tank will serve as a contingency in the event that the POTW discharge must be temporarily discontinued or the leachate holding sump's capacity is exceeded for several days. The cost of this tank is assumed to be $5,300.

Monitoring equipment includes a pH meter, spectrophotometer, and other miscellaneous analytical equipment. This equipment can be purchased for a total cost of $7,000.

Total equipment costs for Case 2 are assumed to be $148,300.

4.6.5 Labor Costs

Routine operating labor requirements for Case 2 are assumed to be about the same as for Case 1 at 7 hours per week. As in Case 1, remote monitoring and alarm systems notify Zenon and the on-site operator of malfunctions in the system. The more complex nature of the feed waste and effluent management system in Case 2 may necessitate more frequent sampling and on-site analytical activities. This estimate assumes that these activities will require an additional 8 hours per month. Assuming a labor charge of $35 per hour, total labor costs for system operation and sampling are estimated to be $16,100 over a 1-year period. Recordkeeping typically associated with remedial actions and POTW discharge limit reporting is assumed to require an additional 4 hours per month; these tasks could be performed by administrative staff, at an average rate of $20 per hour, yielding a total cost of about

$1,000 each year. Based on these criteria, total annual labor costs are assumed to be about $17,100.

4.6.6 Supply Costs

Supplies required for this analysis of the ZenoGem® treatment system include replacement filter membranes for ultrafiltration (UF) and reverse osmoses (RO) modules (Case 1 did not require RO modules), treatment chemicals, carbon columns, disposable PPE, and sampling equipment. According to Zenon, two UF and four RO membranes will be replaced every 3 years, equaling a cost of about $550 per year for the UF membranes and $250 per year for the RO membranes, or a total of $800 per year.

According to Zenon, annual chemical supply requirements include 500 liters of pH control (acid) at $0.30 per liter and 2,225 kilograms of caustic pH control at $0.42 per kilogram; 40 kg of MC-1 cleaner at $6.89 per kilogram, 60 kilograms of MC-4 cleaner at $12.35 per kilogram, and 54 kilograms of phosphorous nutrient at $0.25 per kilogram. Total estimated annual treatment chemical costs for Case 2 are about $2,100.

Annual carbon canister requirements for air emission filtering are assumed to be the same as for Case 1; four canisters at $500 each, for a total cost of $2,000. The system demonstrated at the Nascolite site indicated generally high COD removal efficiency (greater than 85 percent) throughout most of the demonstration without carbon polishing. For this reason, this cost estimate assumes that effluent polishing will not be required to meet POTW discharge standards.

Supplies that will be needed as part of the overall groundwater remediation project include Level D disposable PPE and sampling and field analytical supplies. Disposable PPE typically consists of Tyvek suits, latex inner gloves, nitrile outer gloves, and safety glasses. This PPE is needed during periodic sampling and maintenance activities. Annual disposable PPE costs for this case are assumed to be about $200.

Sampling supplies consist of sample containers, ice, and shipping containers. For routine on-site monitoring, laboratory glassware is also needed. For this case, annual sampling supply costs are assumed to be $300.

Total annual supply costs for Case 2 are estimated to be $5,400.

4.6.7 Utility Costs

Electricity is used to run the pumps and blowers of the treatment system, and for heating, cooling, and lighting in the treatment system shelter building. Water is used for routine cleaning, on-site analyses, and other purposes. This analysis assumes that electrical power lines and water lines are available at the site.

Electricity costs can vary considerably depending on the geographical location of the site and local utility rates. This analysis assumes a constant rate of electricity consumption based on the electrical requirements of the pumps, mixer, and blowers. According to Zenon, the system assumed for Case 2 would typically require about 800 kWh per day, or 292,000 kWh per year. Electricity is assumed to cost $0.09 per kWh, including demand and usage charges. The total annual electricity costs (excluding lighting and HVAC for the building) for Case 2 are about $26,300. Lighting, heat, and water costs for the building are assumed to be about $150 per month, for a total cost of $1,800 per year. These costs result in total assumed utility costs of about $28,000.

4.6.8 Effluent Treatment and Disposal Costs

For Case 2, cleanup goals are assumed to be acceptable for disposal at a POTW without carbon polishing. Based on data from the SITE demonstration and current engineering cost guidance, costs for discharge to the sewer and POTW are assumed to be about $3.00 per thousand gallons. Assuming a treatment rate of 530,000 gallons per year, total costs for effluent treatment and disposal are assumed to be $1,600.

The ZenoGem® system produces air emissions that pass through a carbon column prior to release to the atmosphere. The cost of the carbon column was presented in Section 4.6.6. As a result, no cost for air emissions treatment is incurred.

4.6.9 Residual Waste Management Costs

The only residual waste directly produced during ZenoGem® system operation is a dewatered sludge. Sludge generation rates are highly site specific, and management costs can vary significantly depending on frequency of off-site removal, characterization, transportation costs, disposal requirements, and other factors. For this reason, costs for residual waste disposal can vary by orders of magnitude.

Based on data from the SITE demonstration and additional information provided by Zenon, this estimate assumes that about 30 tons of dewatered sludge will require disposal each year. This material may require management as a hazardous waste. For Case 2, sludge disposal costs are assumed to be about $400 per ton, assuming that the sludge can be stabilized and landfilled, for a total cost of $12,000 per year.

Treatment of air emissions is assumed to generate four spent carbon columns per year. As in Case 1, spent carbon canister disposal costs are assumed to be $175 per canister, resulting in total annual estimated residual waste disposal costs of $12,700.

4.6.10 Analytical Services Costs

Sampling frequency and number of samples are site-specific and will depend on treatment goals, contaminant concentrations, and ARARs of applicable federal, state, and local regulations. This analysis assumes that weekly samples of the treated effluent, and monthly samples of the influent leachate, will be collected and analyzed at an off-site laboratory. Analyses will include VOCs at a cost of $180 per sample; total metals at $140 per sample; COD at $25 per sample; and TOC at $30 per sample. As in Case 1, Case 2 assumes that standard laboratory batch QA/QC samples will be analyzed at no additional cost, and therefore no additional QC sample analytical costs will be incurred. (If required, additional site-specific QC samples would incur additional costs.) Additional on-site analyses (temperature, pH, DO, COD, and TSS) are performed using in-line or field instrumentation during routine operations and incur no additional costs other than labor and equipment rental, which were addressed in other sections. Based on these assumptions, the annual analytical costs are estimated to be about $14,300.

4.6.11 Equipment Maintenance Costs

Annual equipment maintenance costs, excluding labor, are assumed to be about 3 percent of the capital equipment costs, for a total of $4,100. Routine maintenance labor is assumed to requires about 1 hour per week, and occasional backflushing requires about 1 day per month, yielding a total of 148 labor hours per year. At a rate of $35 per hour, maintenance labor costs are about $5,200. Total annual equipment maintenance costs for Case 2 are $9,300.

4.6.12 Site Demobilization Costs

Due to long-term requirements for post-closure care and monitoring, Case 2 assumes only minimal demobilization activities. Site demobilization includes treatment system shutdown, disassembly, and decontamination; treatment equipment removal; and site cleanup and restoration.

A two-person crew earning a total of $70 per hour will work about three 8-hour days to disassemble and decontaminate the system. This labor will cost about $1,700. Case 2 assumes that the equipment has no salvage value, and no costs for removal or disposal are included. However, potential options include resale, scrapping, or long-term storage on site as a contingency for future use, if the need arises. For example, RCRA post-closure care requires 30-year site maintenance and monitoring in many cases. Case 2 also assumes that the influent lines and sewer discharge lines will be plugged and temporarily abandoned; however, the lines will be left in place in the event that they are needed in the future. The building will be left on site as a staging and storage area for other site activities, such as long-term monitoring and maintenance activities.

Based on these criteria, total demobilization costs are assumed to be about $1,700 for Case 2. Sites requiring more extensive site restoration could incur significantly higher demobilization costs.

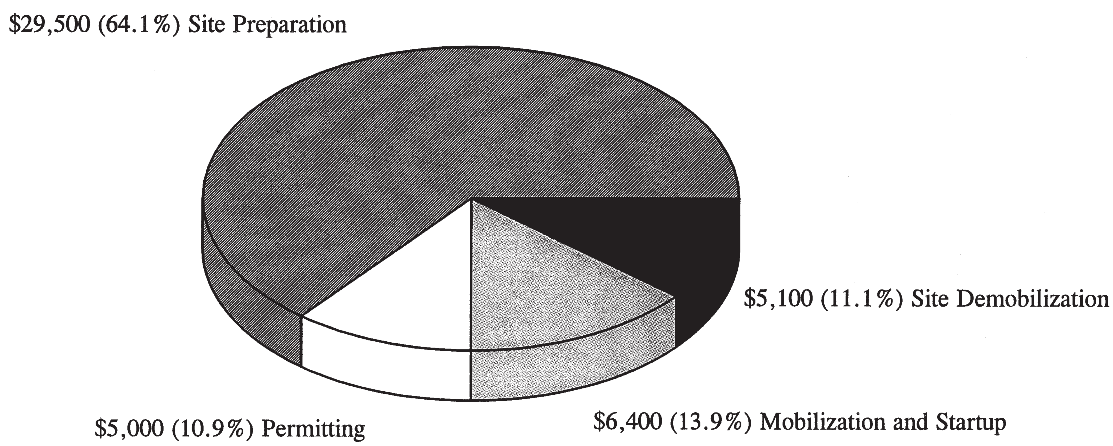
4.7 Conclusions of Economic Analysis

For Case 1, a rented system operating for a 1 year period resulted in total fixed and variable costs of about $263,800, based on the assumptions described in Section 4.3.1. This total results in a cost of $0.50 per gallon of groundwater treated. Figure 4-1 and Figure 4-2 shows the distribution of fixed costs and variable cots for Case 1, respectively.

For Case 2, the total estimated costs for the 10-year leachate treatment period resulted in total and variable costs of about $1,200,000, based on the assumptions described in Section 4.5.1. This total results in a cost of $0.22 per gallon of leachate treated. Figure 4-3 and Figure

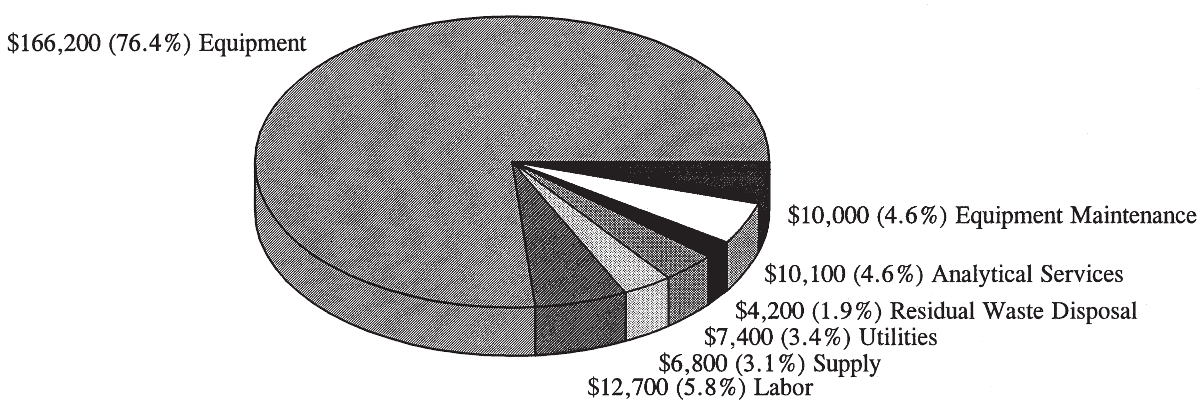
4-4 shows the distribution of fixed costs and variable costs for Case 2, respectively.

For any particular site remediation project, some cost categories, such as utility and supply costs, are heavily dependent on the type of remediation system selected. However, costs for other items (such as groundwater extraction systems) would be about the same regardless of the type of system selected. Some site preparation costs may not be incurred at all sites. Both Case 1 and Case 2 include costs for feed waste retrieval systems (wells or leachate collection systems); at many sites, these features may already exist, or alternate collection systems may be used, resulting in lower costs. For this reason, costs that are significantly affected by operation and use of the ZenoGem® technology are shown in bold in Tables 4-1 and 4-2, and are termed direct costs. Costs are bolded in order to segregate the direct costs of procuring and operating the treatment equipment from the total costs associated with a complete groundwater or leachate treatment project.



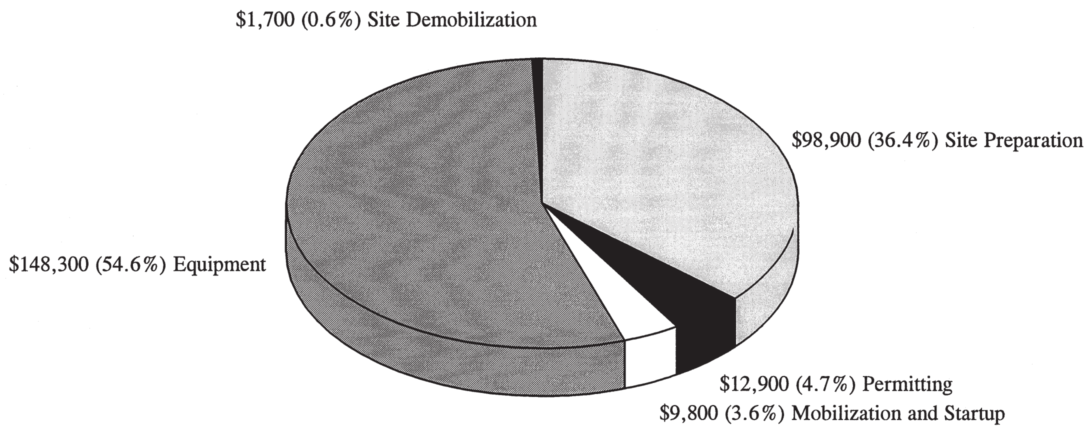
Total estimated fixed costs are $46,000.

Figure 4-1. Case 1 fixed costs.



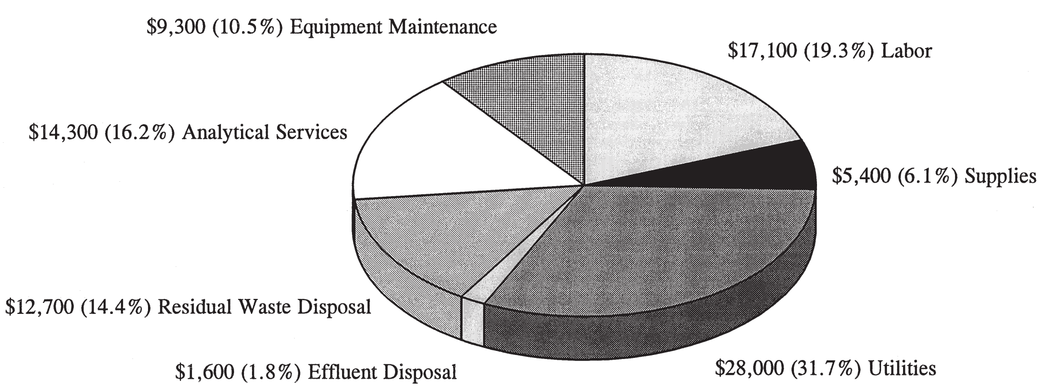
Total estimated variable costs for 1-year period are $217,400.

Figure 4-2. Case 1 variable costs.



Total estimated fixed costs are $271,600.

Figure 4-3. Case 2 fixed costs.



Total estimated variable costs are $88,400 per year, based on an assumed 10-year operating period.

Figure 4-4. Case 2 variable costs.

Section 5
Technology Status

Since the development of the ZenoGem® technology in 1987, Zenon has performed pilot tests and implemented full-scale operational systems for government and private clients on several different types of wastewater, including oily wastewater, metal finishing wastes, aluminum die casting wastewater, circuit board finishing rinse, cleaning solutions containing detergents, alcohol-based cleaning solutions, landfill leachate, aqueous paint-stripping wastes, tannery wastewater, pharmaceutical production washdown wastewater, chemical and petrochemical manufacturing and process solution wastewater, industrial waste transfer station wastewater, glycol deicing fluids, and beverage bottling production wastewater.

In addition, information is available on two demonstrations conducted in Canada and the U.S. At the Canadian Department of National Defense fire fighting school, the ZenoGem® biological unit was demonstrated on wastewater containing burned and unburned fuel residue. The system successfully demonstrated the biodegradation of aqueous foam formulation compounds (AFFF) and simultaneous removal of oil and grease, petroleum hydrocarbons, and suspended solids. The system also was demonstrated at the Army Material Command Watervliet Arsenal, where the ultrafiltration module treated oily wastewater. Results indicated that the ultrafiltration module reduced waste disposal by 70 percent at a significant cost savings.

Each of these processes have one common problem; high strength organic contamination. The technology has been applied to wastewater streams ranging from 5,000 mg/L COD to 100,000 mg/L COD, and flows which range from 100 gpd to 250,000 gpd. The effluent from the ZenoGem® process has met sewer discharge criteria, direct surface water discharge criteria, and for direct recycle to the plant in some cases. In instances where direct recycle and reuse are important and the effluent requires polishing, additional Zenon technologies can be added to achieve the specific recycle objectives.

Zenon continues to develop the technology and the process. Recently, Zenon has developed an innovative ZeeWeed® hollow fiber member as an alternative to the PermaFlow® tubular membrane. Unlike the conventional skid mounted PermaFlow® tubular membrane system, the follow fiber ZeeWeed® membrane is designed for direct installation within existing equalization, aeration or clarification systems. The elimination of skid mounted capital equipment reduces capital expenditures as well as valuable plant floorspace. The ZeeWeed® membrane is an absolute barrier to the passage of biomass and TSS, like the Zenon PermaFlow® tubular membrane, but requires only a fraction of the horsepower for the same flowrate. This membrane has been installed in many industrial and municipal wastewater treatment plants, providing significant operational savings. Its ability to be installed within existing clarification systems and aeration lagoons, along with it's low power consumption requirements, has launched its use into large-scale municipal wastewater treatment plants.

The use of the patented ZenoGem® technology in place of conventional biological treatment technologies is expected to increase. The technology has been proven to be effective, and economically viable in a wide range of applications and markets. As industry changes to meet new demands for product, new and more complicated wastewater treatment problems will continue to emerge. The ZenoGem® technology with the PermaFlow® or ZeeWeed® membrane is well suited to meet these needs.

Section 6
References

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EPA. 1988b. CERCLA *Compliance with Other Environmental Laws: Interim Final*. OSWER. EPA/540/G-89/006. August.

Evans, G. 1990. "Estimating Innovative Treatment Technology Costs for the SITE Program." Journal of Air and Waste Management Association. Volume 40, Number 7. July.

U.S. Department of Energy. 1988. Radioactive Waste Management Order. Department of Energy Order 5820.2A. September.

Appendix A
Vendor Claims

(Note: All information in this appendix was provided by the vendor, Zenon Environmental Inc. Inclusion of any information is at the discretion of Zenon, and does not necessarily constitute U.S. Environmental Protection Agency concurrence or endorsement.)

A.1 Introduction

Zenon Environmental Inc. (Zenon) developed the ZenoGem® process to remove organic compounds from wastewater. The ZenoGem® system consists of a suspended growth, activated sludge system (bioreactor) integrated with an ultrafiltration (UF) membrane system. The UF filters the treated water prior to discharge and the system recycles the biological solids back to the bioreactor and recovers higher- molecular-weight soluble materials that would otherwise pass through conventional clarifiers and filters. These higher-molecular-weight materials are returned to the bioreactor for further biodegradation prior to ultimate discharge.

Ultrafiltration is a pressure-driven, cross-flow filtration process in which water to be processed flows tangentially over the surface of a membrane filter capable of separating both insoluble materials (bacteria, colloids, emulsions, suspended solids) and higher-molecular-weight soluble materials from the treated water. The filtrate and retentate are commonly referred to a permeate and concentrate, respectively. In addition to cross-flow filtration, alternative vacuum based membrane separation systems using Zenon's patented ZeeWeed® membranes are also integrated with the bioreactor in the ZenoGem® process configuration. These ZeeWeed® membranes offer significant economic advantages over the cross-flow filtration configuration particularly at higher wastewater flow rates. In addition, since the membrane is installed directly into the bioreactor, operating facilities may be expanded by three to six times their original design loading without significant alterations to the existing civil works.

The threshold size above which organics are retained by the membrane and below which they pass through the membrane is called the molecular weight cut-off. This value ranges between 0.003 microns to 0.1 microns for ultrafiltration membranes and depends on the specific membrane chemistry and pore size. Integrated membrane bioreactor technology has advanced quickly in recent years as improved membrane chemistries and configurations have produced modules with higher fluxes and lower fouling potential.

A.2 Advantages of the ZenoGem® Process

The ZenoGem® process has the following specific and significant technical advantages over alternative oxidation processes such as activated sludge with clarifiers, fixed film bioreactors, fluidized bed bioreactors or physical-chemical treatment.

A.2.1 Process Less Vulnerable to Upsets

The most common problem encountered in conventional biological systems is the loss of biological solids because of process upsets or changes in the hydraulic or organic loading. In a conventional activated sludge system, clarifier performance depends on the settleability of the floc. If an upset occurs and a difficult-to-settle "pin floc" or "filamentous floc" forms, the biological solids can easily be lost. In the short term, an effluent high in suspended solids and BOD_5 will be produced. The effluent BOD_5 will remain high until the biological population has been restored. If an upset occurs in a fixed film-type biological system (rotating biological contractor, fluidized bed) and sloughing occurs, these solids can be lost from the system resulting in poor quality effluent.

In the ZenoGem® process, the effluent quality does not depend on the settleability of the biological floc. The biological solids will be retained even if an upset occurs in the bioreactor. The UF membranes are very robust and experience has proven that the risk of failure resulting in the loss of biological solids is very remote.

A.2.2 Improved Effluent Quality

The ultrafiltration membrane provides virtually absolute suspended solid-liquid separation, thus preventing the loss of biological solids in the effluent. Furthermore, certain organics, including free and emulsified oil and grease, are retained thereby further improving the effluent quality.

A.2.3 Reduced Sludge Production

In contrast with other biological waste treatment processes, the volume of sludge produced is significantly reduced and operation at high solids retention times (up to 100 days) is possible.

A.2.4 Improved Biological Degradation of Retained Organics

Soluble organics in the wastewater of a size greater than the membrane molecular weight cut-off are retained in the bioreactor for a period of 15 to 50 times longer than the hydraulic retention time of the bioreactor (based on wastewater flow rate). As a result, the biological population has a longer time to mineralize the organics and better degrade them.

A.2.5 Accurate Control of Sludge Age

Because virtually no solids are lost from the permeate (discharge) stream and the wasting of biological solids is strictly restricted, the sludge age can be very accurately controlled, and bioreactor performance can be optimized to the specific wastewater characteristics. Ammonia also may be removed through nitrification.

A.2.6 Improved Oxygen Transfer Efficiency

Oxygen transfer in ZenoGem® systems is improved over competitive systems because the biological cells in the bioreactor are more dispersed and oxygen diffuses more rapidly to all the cells. In competitive systems, oxygen transfer to the cells at or near the center of a floc or near the surface of a fixed film system is restricted by the cells in the immediate vicinity. With improved oxygen transfer efficiency, less aeration is required and operating costs are reduced.

A.2.7 Smaller Bioreactor Size

Since settleability of sludge is not a concern in the ZenoGem® process, high biomass levels can be maintained within the bioreactor. Whereas conventional bioreactors cannot maintain higher than 5,000 - 10,000 milligrams per liter (mg/L) of bacteria, measured as mixed liquor volatile suspended solids (MLVSS), the ZenoGem® process is operated at 20,000 - 30,000 mg/L MLVSS. This difference means that the ZenoGem® bioreactor can be three to six times smaller than a conventional bioreactor, or the same size bioreactor can handle three to six times more wastewater provided adequate aeration in supplied.

A.3 Application of ZenoGem® Process

The ZenoGem® technology has developed quickly in recent years as improved membrane chemistries and configurations have produced modules with higher fluxes and lower fouling potentials. The ZenoGem® process is ideally suited for anyone or more of the following:

- Wastewater containing significant quantities of emulsified oil and grease
- Wastewater containing suspended solids that do not settle easily
- Conventional treatment processes cannot produce an effluent that consistently meets the discharge requirements
- Sludge disposal costs contribute significantly to the treatment cost
- Treated water may be reused within the plant as make-up water
- A long solids retention time is desirable
- Physical retention of certain soluble components is critical to achieving the treatment objectives

- Wastewater contains potentially inhibitory or complex organic compounds

- The current biological treatment process requires upgrading or expansion

A.4 Case Studies

A.4.1 Landfill Leachate Treatment - Dectra-Laimont, France

Dectra-Laimont is a 9-hectare Class I landfill in France that began operations in 1983. Since 1987, the landfill received wastes only from local chemical and metal processing industries. Leachate is pumped from ten shafts at various locations throughout the site to a 1500 cubic meters (m^3)-capacity aerated holding pond. Each day, approximately 10 m^3 of leachate is produced. Effluent discharge from the site is direct to surface water and consequent discharge criteria are strict. In addition, the leachate composition is variable with frequent fluctuations in organic strength and other compounds.

A.4.2 GM Mansfield

Zenon installed a ZenoGem® system followed by double-pass reverse osmosis to treat the leachate and discharge direct to the environment. The ZenoGem® system operated at GM's Cadillac Luxury Car Division in Mansfield, Ohio to treat 40,000 gallons per day of oily wastewater from tooling, cooling tower blowdown, steam cleaning booths, baler house, floor washing, and boiler blowdown. The wastewater contained primarily emulsified oil and grease, suspended solids, and heavy metals.

The wastewater is directed through grit screens for gross solids removal followed by free oil removal by corrugated plated interceptors. The wastewater then flows to an equalization tank and finally to the ZenoGem® bioreactor. Urea and phosphoric acid are added as nutrient supplements and sodium hydroxide is used to adjust the pH.

The system was commissioned in 1992 and has consistently met or exceeded discharge criteria as illustrated in Table A-1. The ZenoGem® system is particularly amenable to the treatment of oily wastewater because the ultrafiltration membrane rejects the high-molecular-weight oil and grease and keeps the material in the bioreactor for the entire sludge retention time, not just the hydraulic retention time like conventional clarifier based activated sludge systems. This advantage allows microorganisms more time to mineralize the oil and grease and leads to an extremely high-quality effluent.

A.4.3 Closed-Loop, Zero-Discharge ZenoGem[7] /RO System, Saltillo, Mexico

Zenon designed, manufactured and installed a closed-loop, zero-discharge system for Chrysler Mexico's engine manufacturing plant in Saltillo, Mexico. The plant treats as much as 40,000 gallons per day of oily wastewater of sufficient quality that it can be recycled directly within the plant. The ability to recycle wastewater is extremely important in Saltillo as the fresh water is limited tp groundwater. Continued discharge of even mildly contaminated effluent would eventually seriously impact the aquifer.

In the process, free oil is removed and the wastewater is directed to the ZenoGem® system, where the oil and grease and other organic fractions are removed. The ultrafiltration permeate is then directed to a reverse osmosis unit for polishing and removal of dissolved inorganics and metals. The unit has been operating for over 1 year, producing high-quality water for reuse in the engine manufacturing plant.

Based on the performance data presented in Table A-2 the ZenoGem® unit is extremely effective at the removal of COD while the RO simply provides final polishing.

A.5 ZenoGem® Installations

The following table presents a summary of some of the full-scale ZenoGem® installation that are operating on a variety of different wastewaters worldwide.

Table A-1. GM Mansfield ZenoGem® Performance

Parameters	Feed (mg/L)	ZenoGem® Permeate (mg/L)	Discharge Criteria (mg/L)
COD	*5539*	*631*	-
BOD	-	*91*	*200*
TO&G	*1330*	*15*	*50*
TPH	*1220*	*9*	*35*

Table A-2. Chrysler Mexico ZenoGem®/ RO Performance

Parameter	Feed	ZenoGem® Permeate	RO Permeate
COD	3100 mg/L	390 mg/L	7 mg/L

Table A-3. Summary of ZenoGem® Installations

Plant	Wastewater	Capacity (gpd)
GM Windsor, Ontario, Canada	Oily	260,000
GM Mansfield, Ohio, USA	Oily	40,000
Chrysler Mexico, Saltillo, Mexico	Oily	40,000
GM Ramos Arizipe, Mexico	Oily	40,000
Secifarma, Milan, Italy	Pharmaceutical	32,000
Ferrero, Milan, Italy	Food	27,000
Driesen Tannery, Netherlands	Tannery	26,000
Recept Composting, Netherlands	Leachate	7,000
Dectra Landfill, France	Leachate	3,000
Orlick Industries, Ontario, Canada	Oily	2,000
IBM, Toronto, Ontario	Spent Cleaner	1,000

Appendix B
Summary of Field Data

Table B-1. September Field Measurements

	TEMPERATURE (Degrees Celsius)				pH				DISSOLVED OXYGEN (mg/L)			
DATE	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
02-Sep-94	26	31	30	31	6.39	7.73	7.75	7.98	8.10	0.10	0.30	8.20
03-Sep-94	24	31	31	30	6.34	7.71	7.80	8.01	4.70	0.00	0.00	5.20
04-Sep-94	25	31	31	31	6.41	7.70	7.75	7.94	2.30	0.00	0.00	5.60
05-Sep-94	26	31	31	31	6.23	7.64	7.66	7.85	2.80	0.00	0.00	5.70
06-Sep-94	28	32	32	32	6.28	7.50	7.51	7.65	1.90	0.00	0.00	5.00
07-Sep-94	28	33	33	33	6.27	7.26	7.24	7.38	1.90	0.10	0.10	4.00
08-Sep-94	27	32	32	32	6.22	7.31	7.40	7.72	1.90	1.00	2.00	4.50
09-Sep-94	28	32	32	32	6.14	7.32	7.31	7.45	2.00	0.50	0.50	4.50
10-Sep-94	29	32	33	33	5.92	6.80	6.83	6.95	2.00	1.00	1.40	2.50
11-Sep-94	27	31	32	32	6.13	6.70	6.73	6.88	1.40	1.10	0.80	2.50
12-Sep-94	26	32	32	31	6.21	6.82	6.72	7.03	1.70	0.00	0.00	3.90
13-Sep-94	26	33	34	33	6.28	7.07	7.05	7.27	2.30	0.10	0.00	2.30
14-Sep-94	28	35	35	35	6.17	7.16	7.31	7.91	1.60	0.40	0.00	2.50
15-Sep-94	27	32	32	32	6.30	7.32	7.42	7.56	3.60	1.00	1.00	6.00
16-Sep-94	26	32	32	33	5.86	7.00	7.16	7.09	3.40	0.70	0.80	4.60
17-Sep-94	26	32	32	32	6.01	6.94	7.16	7.32	3.80	0.80	0.80	2.90
18-Sep-94	25	32	32	33	5.94	6.93	7.44	7.13	3.00	1.20	1.00	4.00
19-Sep-94	27	33	33	33	6.17	7.21	7.19	7.70	3.00	0.10	0.00	3.20
20-Sep-94	24	33	33	32	6.32	7.42	7.22	7.40	4.50	0.30	0.50	3.70
21-Sep-94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22-Sep-94	25	32	32	33	6.10	7.18	7.33	7.50	2.00	0.30	0.80	3.30
23-Sep-94	27	33	33	34	6.09	7.14	7.29	7.51	3.50	0.90	1.40	2.80
24-Sep-94	25	31	31	32	6.40	7.30	7.34	7.44	2.40	1.00	1.20	3.70
25-Sep-94	29	31	31	31	6.47	7.32	7.45	7.58	5.30	0.70	1.40	7.70
26-Sep-94	24	29	32	31	6.45	7.22	7.26	7.56	2.30	0.80	1.40	2.90
27-Sep-94	25	30	32	31	6.75	7.34	7.59	7.84	2.70	0.80	0.60	2.30
28-Sep-94	24	32	32	32	6.27	7.06	7.16	7.31	3.10	0.80	0.60	3.10
29-Sep-94	23	31	33	33	6.34	6.94	7.20	7.29	5.50	0.60	0.40	3.90
30-Sep-94	24	33	34	34	6.66	6.79	6.93	7.04	5.80	0.70	0.80	2.80

S = Sampling Port

Table B-2. October Field Measurements

DATE	TEMPERATURE (degrees Celsius) S1	S2	S3	S4	pH S1	S2	S3	S4	DISSOLVED OXYGEN (mg/L) S1	S2	S3	S4
01-Oct-94	24	32	33	33	6.36	7.10	7.10	7.25	3.60	0.80	0.50	1.40
02-Oct-94	25	34	34	34	6.48	7.08	7.20	7.29	3.10	0.40	0.70	2.00
03-Oct-94	23	32	32	31	6.92	7.66	7.73	7.91	5.00	0.00	0.10	2.50
04-Oct-94	23	31	32	32	6.34	6.99	7.32	7.24	4.70	0.00	0.00	2.40
05-Oct-94	22	29	30	30	5.76	6.46	6.73	6.96	3.90	0.70	0.80	4.10
06-Oct-94	26	28	30	30	6.08	6.53	6.82	7.14	3.60	0.80	0.60	2.90
07-Oct-94	28	31	31	32	6.21	6.47	6.93	7.21	3.80	0.70	0.80	2.70
08-Oct-94	23	30	31	31	6.08	6.40	6.70	6.56	3.50	0.60	0.80	2.00
09-Oct-94	23	31	33	33	6.05	6.07	6.80	6.90	4.20	0.70	0.90	3.20
10-Oct-94	23	31	32	32	6.04	6.09	6.92	7.03	3.40	0.00	0.00	2.20
11-Oct-94	25	28	29	29	6.28	6.84	6.97	7.35	3.20	0.10	0.00	1.20
12-Oct-94	20	29	30	30	6.67	6.83	6.71	7.05	4.60	0.60	0.90	2.50
13-Oct-94	22	31	32	31	6.74	6.98	7.08	7.42	3.60	0.80	0.90	2.40
14-Oct-94	23	30	30	30	6.62	6.84	6.96	7.23	3.60	0.90	1.00	4.20
15-Oct-94	23	31	33	34	6.72	6.93	7.10	7.38	4.20	0.80	0.60	3.20
16-Oct-94	21	34	35	34	6.18	6.94	7.00	7.06	5.50	0.00	0.00	3.80
17-Oct-94	22	34	35	34	6.42	7.05	7.00	7.04	2.70	0.70	0.90	0.70
18-Oct-94	22	33	34	34	6.44	7.01	7.07	7.09	3.60	0.70	0.80	1.10
19-Oct-94	23	33	35	35	6.34	6.93	6.99	7.14	3.20	0.40	0.90	2.40
20-Oct-94	22	34	34	34	6.44	6.87	7.03	7.13	3.60	0.70	1.00	4.10
21-Oct-94	24	33	34	34	6.40	6.93	7.04	7.10	3.80	0.90	0.60	4.10
22-Oct-94	24	32	32	32	6.42	6.89	7.01	7.14	2.80	0.70	0.40	3.10
23-Oct-94	26	34	35	34	6.22	7.04	7.10	7.15	3.70	0.60	0.80	2.00
24-Oct-94	25	33	34	34	6.36	7.06	7.15	7.20	2.80	0.70	1.00	3.20
25-Oct-94	24	31	35	34	6.44	7.14	7.26	7.22	5.60	0.80	1.00	7.70
26-Oct-94	24	31	32	32	6.28	6.54	6.94	7.14	3.30	0.90	0.60	3.90
27-Oct-94	22	26	33	33	6.14	6.74	7.15	7.17	3.07	0.00	0.00	1.22
28-Oct-94	22	27	34	33	6.08	6.82	7.12	7.20	3.02	0.00	0.00	1.62
29-Oct-94	25	34	33	34	6.23	7.39	7.47	7.57	3.30	0.60	0.40	5.30
30-Oct-94	25	31	34	33	6.34	7.55	7.52	7.79	3.60	0.00	0.00	3.50

S = Sampling Port

Table B-3. November Field Measurements

DATE	TEMPERATURE (Degrees Celsius) S1	S2	S3	S4	S10	pH S1	S2	S3	S4	S10	DISSOLVED OXYGEN (mg/L) S1	S2	S3	S4	S10
01-Nov-94	23	34	35	39		6.40	7.37	7.41	7.42	NA	2.85	0.00	0.00	1.05	NA
02-Nov-94	22	31	32	33	22	6.35	7.21	7.21	7.26	7.74	2.47	0.00	0.00	1.16	1.93
03-Nov-94	22	34	34	34		6.45	7.29	7.32	7.44	NA	3.67	0.00	0.02	2.25	NA
04-Nov-94	28	34	34	34	40	6.31	7.58	7.52	7.65	7.75	0.65	0.00	0.00	3.75	0.66
05-Nov-94	24	33	34	33		6.47	7.23	7.25	7.30	NA	4.07	0.01	0.02	2.05	NA
06-Nov-94	24	34	35	34		6.50	7.32	7.35	7.35	NA	3.83	0.01	0.01	2.83	NA
07-Nov-94	21	35	36	36	20	6.16	7.29	7.31	7.34	7.72	4.38	0.00	0.04	2.04	4.20
08-Nov-94	22	36	37	38		6.17	7.46	7.50	7.60	NA	4.89	0.01	0.01	2.24	NA
09-Nov-94	25	37	37	39	32	6.15	7.47	7.52	7.59	7.61	6.14	0.00	0.43	4.95	6.10
10-Nov-94	23	36	37	37		6.38	7.76	7.82	7.83	NA	5.74	0.00	0.56	2.83	NA
11-Nov-94	22	38	38	37	24	6.03	7.51	7.54	7.63	7.81	10.27	0.00	0.02	3.76	6.74
12-Nov-94	21	33	36	37		6.14	7.57	7.65	7.66	NA	6.48	0.01	0.03	2.76	NA
13-Nov-94	24	37	39	39		6.22	7.67	7.69	7.84	NA	6.99	0.01	0.02	2.75	NA
14-Nov-94	23	39	39	39	33	6.53	7.85	7.79	7.94	7.91	3.80	0.00	0.01	2.84	2.15
15-Nov-94	24	37	40	39		6.61	7.96	8.02	8.03	NA	6.15	0.02	0.16	2.59	NA
16-Nov-94	23	35	33	38	10	6.33	7.92	8.00	8.07	8.09	7.59	0.01	0.11	2.63	5.08
17-Nov-94	23	33	37	36		6.44	7.94	7.98	8.05	NA	6.23	0.03	0.02	1.67	NA
18-Nov-94	22	39	39	39	13	6.36	7.81	7.84	7.98	8.21	4.50	0.00	0.01	0.74	3.24
19-Nov-94	24	32	39	39		6.36	7.41	7.79	7.81	NA	5.73	0.06	0.04	1.55	NA
20-Nov-94	36	32	37	36		6.50	7.52	7.72	7.74	NA	4.30	0.07	0.50	2.24	NA
21-Nov-94	21	34	38	38	12	6.46	7.83	7.98	8.05	8.18	6.47	0.09	0.00	2.53	6.07
22-Nov-94	22	32	36	36		6.30	7.28	7.33	7.38	NA	6.69	0.00	0.00	1.18	NA
23-Nov-94	24	33	36	35	5	6.36	7.75	7.80	7.96	8.00	NA	0.01	0.01	0.77	3.09

S = Sampling Port

Table B-4. Total Liquid Flow of Influent Stream (M1)

Date	Pump Reading (percent gpm) 07:00 am	11:00 am	3:00 am	Average	Calculated Flow (gpm)*	Daily Flow (Liters)	Daily Flow (gallons)
02-Sep-94	1	1	1	1	0.692	3,772	996
03-Sep-94	1	1	1	1	0.692	3,772	996
04-Sep-94	1	1	1	1	0.692	3,772	996
05-Sep-94	1	1	1	1	0.692	3,772	996
06-Sep-94	1	1	1	1	0.692	3,772	996
07-Sep-94	1	1	1	1	0.692	3,772	996
08-Sep-94	0.25	0.25	0.25	0.250	0.360	1,961	518
09-Sep-94	0.25	0.25	0.25	0.250	0.360	1,961	518
10-Sep-94	0.25	0.25	0.25	0.250	0.360	1,961	518
11-Sep-94	0.25	0.25	0.26	0.253	0.361	1,969	520
12-Sep-94	0.25	0.25	0.25	0.250	0.360	1,961	518
13-Sep-94	0.25	0.25	0.25	0.250	0.360	1,961	518
14-Sep-94	0.25	0.26	0.26	0.257	0.363	1,977	522
15-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
16-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
17-Sep-94	0.25	0.26	0.26	0.257	0.363	1,977	522
18-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
19-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
20-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
21-Sep-94	0	0	0	0	0	0	0
22-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
23-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
24-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
25-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
26-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
27-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
28-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
29-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
30-Sep-94	0.26	0.26	0.26	0.260	0.364	1,985	524
01-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
02-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
03-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
04-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
05-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
06-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
07-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
08-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
09-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
10-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
11-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
12-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
13-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
14-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
15-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
16-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524
17-Oct-94	0.26	0.26	0.26	0.260	0.364	1,985	524

Table B-4. Total Liquid Flow of Influent Stream (M1) (continued)

Date	Pump Reading (percent gpm) 07:00 am	11:00 am	3:00 am	Average	Calculated Flow (gpm)*	Daily Flow (Liters)	Daily Flow (gallons)
18-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
19-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
20-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
21-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
22-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
23-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
24-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
25-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
26-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
27-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
28-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
29-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
30-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
31-Oct-94	0.26	0.26	0.26	0.260	0.364	1985	524
01-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
02-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
03-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
04-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
05-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
06-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
07-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
08-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
09-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
10-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
11-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
12-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
13-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
14-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
15-Nov-94	0.26	0.26	0.26	0.260	0.364	1985	524
16-Nov-94	0.26	0.2	0.26	0.240	0.355	1937	512
17-Nov-94	0.26	0.26	0.2	0.240	0.355	1937	512
18-Nov-94	0.18	0.18	0.18	0.180	0.329	1792	473
19-Nov-94	0.18	0.18	0.18	0.180	0.329	1792	473
20-Nov-94	0.41	0.41	0.41	0.410	0.431	2347	620
21-Nov-94	0.41	0.41	0.41	0.410	0.431	2347	620
22-Nov-94	0	0	0	0.000	0.000	0	0
23-Nov-94	16	0	0	5.333	2.612	6228	1645
Total						**175,831**	**46,455**

Table B-5. Total Liquid Flow of Effluent Stream (M4)

Date	Pump Reading (gpm) 7:00 am	11:00 am	3:00 am	Average Flow (gpm)	Calculated Flow (gpm)*	Daily Flow (Liters)	Daily Flow (Gallons)
02-Sep-94	0.5	0.51	0.47	0.49	0.485	2643	698
03-Sep-94	0.53	0.555	0.52	0.54	0.526	2866	757
04-Sep-94	0.54	0.53	0.53	0.53	0.524	2857	755
05-Sep-94	0.53	0.5	0.52	0.52	0.508	2768	731
06-Sep-94	0.33	0.28	0.26	0.29	0.285	1554	410
07-Sep-94	0.1	0.1	0.1	0.10	0.098	536	142
08-Sep-94	0.1	0.1	0.1	0.10	0.098	536	142
09-Sep-94	1.04	1.12	1.06	1.07	1.055	5750	1519
10-Sep-94	1.06	0.97	0.98	1.00	0.986	5375	1420
11-Sep-94	0.88	0.89	0.89	0.89	0.872	4750	1255
12-Sep-94	0.78	0.77	0.69	0.75	0.734	4000	1057
13-Sep-94	0.67	0.69	0.67	0.68	0.665	3625	958
14-Sep-94	0.69	0.64	0.65	0.66	0.649	3536	934
15-Sep-94	0.64	0.6	0.65	0.63	0.619	3375	892
16-Sep-94	0.5	0.58	0.6	0.56	0.550	3000	793
17-Sep-94	0.58	0.6	0.58	0.59	0.577	3143	830
18-Sep-94	0.6	0.6	0.6	0.60	0.590	3214	849
19-Sep-94	0.58	0.54	0.52	0.55	0.537	2929	774
20-Sep-94	0.52	0.5	0.48	0.50	0.491	2679	708
21-Sep-94	0	0	0	0.00	0.000	0	0
22-Sep-94	0.5	0.49	0.48	0.49	0.482	2625	694
23-Sep-94	0.58	0.49	0.48	0.52	0.508	2768	731
24-Sep-94	0.55	0.58	0.58	0.57	0.560	3054	807
25-Sep-94	0.53	0.56	0.55	0.55	0.537	2929	774
26-Sep-94	0.55	0.47	0.54	0.52	0.511	2786	736
27-Sep-94	0.52	0.53	0.58	0.54	0.534	2911	769
28-Sep-94	0.43	0.4	0.39	0.41	0.400	2179	576
29-Sep-94	0.36	0.32	0	0.34	0.334	1821	481
30-Sep-94	0.47	0.41	0.43	0.44	0.429	2339	618
01-Oct-94	0.47	0.47	0.47	0.47	0.462	2518	665
02-Oct-94	0.48	0.47	0.46	0.47	0.462	2518	665
03-Oct-94	0.47	0.46	0.5	0.48	0.469	2554	675
04-Oct-94	0.52	0.46	0.42	0.47	0.459	2500	661
05-Oct-94	0.52	0.48	0.46	0.49	0.478	2607	689
06-Oct-94	0.41	0.42	0.44	0.42	0.416	2268	599
07-Oct-94	0.42	0.42	0.46	0.43	0.426	2322	613
08-Oct-94	0.39	0.38	0.4	0.39	0.383	2089	552
09-Oct-94	0.36	0.36	0.46	0.39	0.387	2107	557
10-Oct-94	0.39	0.42	0.43	0.41	0.406	2214	585
11-Oct-94	0.31	0	0.76	0.54	0.526	2866	757
12-Oct-94	0.45	0.45	0.45	0.45	0.442	2411	637
13-Oct-94	0.45	0.46	0.58	0.50	0.488	2661	703
14-Oct-94	0.48	0.46	0.51	0.48	0.475	2589	684
15-Oct-94	0.53	0.55	0.5	0.53	0.518	2822	745
16-Oct-94	0.57	0.53	0.54	0.55	0.537	2929	774
17-Oct-94	0.53	0.53	0.53	0.53	0.521	2839	750

Table B-5. Total Liquid Flow of Effluent Stream (M4) (continued)

Date	Pump Reading (gpm) 7:00 am	11:00 am	3:00 am	Average Flow (gpm)	Calculated Flow (gpm)*	Daily Flow (Liters)	Daily Flow (Gallons)
18-Oct-94	0.45	0.48	0.47	0.47	0.459	2500	661
19-Oct-94	0.49	0.47	0.45	0.47	0.462	2518	665
20-Oct-94	0.46	0.46	0.44	0.45	0.446	2429	642
21-Oct-94	0.49	0.47	0.48	0.48	0.472	2572	679
22-Oct-94	0.5	0.48	0.52	0.50	0.491	2679	708
23-Oct-94	0.53	0.52	0.51	0.52	0.511	2786	736
24-Oct-94	0.5	0.51	0.5	0.50	0.495	2697	712
25-Oct-94	0.51	0.49	0.49	0.50	0.488	2661	703
26-Oct-94	0.51	0.5	0.5	0.50	0.495	2697	712
27-Oct-94	0.5	0.5	0.51	0.50	0.495	2697	712
28-Oct-94	0.52	0.56	0.51	0.53	0.521	2839	750
29-Oct-94	0.54	0.55	0.54	0.54	0.534	2911	769
30-Oct-94	0.54	0.59	0.61	0.58	0.570	3107	821
31-Oct-94	0.66	0.68	0.71	0.68	0.672	3661	967
01-Nov-94	0.79	0.77	0.8	0.79	0.773	4215	1113
02-Nov-94	0.8	0.8	0.81	0.80	0.790	4304	1137
03-Nov-94	0.81	0.79	0.76	0.79	0.773	4215	1113
04-Nov-94	0.73	0.79	0.73	0.75	0.737	4018	1062
05-Nov-94	0.78	0.77	0.8	0.78	0.770	4197	1109
06-Nov-94	0.69	0.76	0.82	0.76	0.744	4054	1071
07-Nov-94	0.88	0.87	0.91	0.89	0.872	4750	1255
08-Nov-94	0.95	0.97	0.99	0.97	0.953	5197	1373
09-Nov-94	1	0.98	1	0.99	0.976	5322	1406
10-Nov-94	0.97	0.99	0	0.98	0.963	5250	1387
11-Nov-94	1.02	1.01	1.03	1.02	1.003	5465	1444
12-Nov-94	1.01	1.01	0.94	0.99	0.970	5286	1397
13-Nov-94	1.02	1.04	1.03	1.03	1.012	5518	1458
14-Nov-94	0.99	1.03	0.92	0.98	0.963	5250	1387
15-Nov-94	0.7	0.85	0.83	0.79	0.780	4250	1123
16-Nov-94	0.95	0.98	1	0.98	0.960	5233	1382
17-Nov-94	0.96	0.92	0.95	0.94	0.927	5054	1335
18-Nov-94	1.06	1.09	1.04	1.06	1.045	5697	1505
19-Nov-94	1.02	0.91	1.01	0.98	0.963	5250	1387
20-Nov-94	0.94	0.9	0.77	0.87	0.855	4661	1231
21-Nov-94	0.75	0.69	0.69	0.71	0.698	3804	1005
22-Nov-94	0.7	0.52	0.4	0.54	0.531	2893	764
23-Nov-94	0.42	0.41	0	0.42	0.408	2223	587
Total						**270,221**	**71,392**

Table B-6. Oxidation Reduction Potential (mV)

Oxidation Reduction Potential (mV)

DATE	S1	S2	S3	S4	S10
07-Sep-94	530	2	-37	170	NA
14-Sep-94	170	-510	-470	230	NA
05-Oct-94	319	-62.5	NA	282	NA
19-Oct-94	335	NA	NA	266	NA
02-Nov-94	257	-94	-101	252	246
09-Nov-94	258	NA	-108	242	224
16-Nov-94	NA	NA	NA	NA	NA
23-Nov-94	330	195	120	227	360

S = Sampling Port

Appendix C
Summary of Analytical Data

Table C-1. MMA Analytical Results - September

DATE	S1	S2	S3	S4	S10
02-Sep-94	1430	<0.020	<0.020	0.324	NA
03-Sep-94	NA	NA	NA	NA	NA
04-Sep-94	1470	NA	NA	0.029	NA
05-Sep-94	1300	<0.100	<0.100	0.062	NA
06-Sep-94	1630	NA	NA	0.073	NA
07-Sep-94	1810	0.009	0.251	0.287	NA
08-Sep-94	1950	NA	NA	0.086	NA
09-Sep-94	1660	0.017	0.325	0.477	NA
10-Sep-94	NA	NA	NA	NA	NA
11-Sep-94	1370	NA	NA	11.600	NA
12-Sep-94	1600	15.600	18.800	16.800	NA
13-Sep-94	1550	NA	NA	7.270	NA
14-Sep-94	1860	<0.020	<0.020	0.007	NA
15-Sep-94	2160	NA	NA	0.015	NA
16-Sep-94	567	<0.100	<0.200	<0.010	NA
17-Sep-94	NA	NA	NA	NA	NA
18-Sep-94	2250	NA	NA	<0.010	NA
19-Sep-94	2580	<0.020	<0.020	<0.010	NA
20-Sep-94	NA	NA	NA	NA	NA
21-Sep-94	2340	NA	NA	<0.010	NA
22-Sep-94	2740	NA	NA	<0.010	NA
23-Sep-94	2300	<0.020	<0.020	<0.010	NA
24-Sep-94	NA	NA	NA	NA	NA
25-Sep-94	2450	NA	NA	0.018	NA
26-Sep-94	2080	<0.020	<0.020	<0.010	NA
27-Sep-94	2460	NA	NA	<0.010	NA
28-Sep-94	2290	<0.020	<0.020	<0.020	NA
29-Sep-94	2890	NA	NA	0.065	NA
30-Sep-94	3630	<0.040	<0.040	<0.010	NA

< = Less than the reported value. Reported value is the Detection Limit.

S = Sampling Port

Table C-2. MMA Analytical Results - October

DATE	S1	S2	S3	S4	S10
02-Oct-94	1760	NA	NA	0.050	NA
03-Oct-94	1690	<0.040	<0.040	<0.010	NA
04-Oct-94	1960	NA	NA	<0.010	NA
05-Oct-94	1890	<0.040	<0.040	<0.010	NA
06-Oct-94	1440	NA	NA	<0.010	NA
07-Oct-94	1600	<0.020	<0.020	<0.010	NA
08-Oct-94	NA	NA	NA	NA	NA
09-Oct-94	1600	NA	NA	<0.015	NA
10-Oct-94	1840	<0.020	<0.020	<0.010	NA
11-Oct-94	1680	NA	NA	<0.010	NA
12-Oct-94	1650	<0.020	<0.020	<0.010	NA
13-Oct-94	1820	NA	NA	<0.007	NA
14-Oct-94	1740	<0.020	<0.040	<0.010	NA
15-Oct-94	NA	NA	NA	NA	NA
16-Oct-94	1790	NA	NA	<0.010	NA
17-Oct-94	1910	<0.020	<0.020	<0.010	NA
18-Oct-94	1760	NA	NA	<0.010	NA
19-Oct-94	1560	<0.020	<0.020	<0.010	NA
20-Oct-94	1980	NA	NA	<0.010	0.288
21-Oct-94	1780	<0.020	<0.020	<0.010	NA
22-Oct-94	NA	NA	NA	NA	NA
23-Oct-94	1900	NA	NA	<0.010	NA
24-Oct-94	2410	<0.020	<0.020	<0.010	NA
25-Oct-94	2620	NA	NA	<0.010	NA
26-Oct-94	2120	<0.100	<0.100	<0.020	NA
27-Oct-94	2340	NA	NA	<0.020	<0.020
28-Oct-94	2220	<0.020	<0.020	<0.020	<0.020
29-Oct-94	NA	NA	NA	NA	NA
30-Oct-94	2150	NA	NA	<0.020	NA
31-Oct-94	2210	<0.020	<0.040	<0.020	<0.020

< = Less than the reported value. Reported value is the Detection Limit.

S = Sampling Port

Table C-3. MMA Analytical Results - November

DATE	TIME*	S1	S2	S3	S4	S10
01-Nov-94		1890	NA	NA	<0.010	NA
02-Nov-94		2060	<0.020	<0.020	<0.010	<0.010
03-Nov-94		2120	NA	NA	<0.010	NA
04-Nov-94		2220	<0.100	<0.100	<0.010	<0.010
05-Nov-94		NA	NA	NA	NA	NA
06-Nov-94		2050	NA	NA	<0.010	NA
07-Nov-94		2360	<0.050	<0.100	<0.100	<0.010
08-Nov-94	800	2020	<0.020	<0.020	<0.020	<0.020
08-Nov-94	1000	7480	<0.020	<0.040	<0.020	<0.020
08-Nov-94	1200	6500	0.011	<0.040	<0.020	<0.020
08-Nov-94	1400	7140	<0.050	<0.400	<0.020	<0.020
09-Nov-94		6220	<0.100	<0.100	<0.010	<0.010
10-Nov-94		9240	NA	NA	<0.010	NA
11-Nov-94		6480	<0.040	<0.100	<0.010	<0.010
12-Nov-94		NA	NA	NA	NA	NA
13-Nov-94		7110	NA	NA	0.005	NA
14-Nov-94		7420	<0.200	0.013 J	<0.010	0.005
15-Nov-94		7830	NA	NA	0.004	NA
16-Nov-94		8640	<0.050	0.002 J	<0.010	<0.010
17-Nov-94		7470	NA	NA	0.005	NA
18-Nov-94		7690	<0.020	<0.050	<0.010	<0.010
19-Nov-94		NA	NA	NA	NA	NA
20-Nov-94		9450	NA	NA	0.004	NA
21-Nov-94		8420	<0.010	<0.025	0.005	0.005
22-Nov-94		9500	NA	NA	0.123	NA
23-Nov-94		9090	0.011 J	<0.006 J	0.021	<0.010

< = Less than the reported value.
Reported value is the Detection Limit.
* = Shock Loading

S = Sampling Port

Table C-4. TCL VOC Concentrations - September

DETECTED TCL VOC COMPOUNDS (µg/L)	SEPTEMBER													
	02-Sep-94	03-Sep-94	04-Sep-94	05-Sep-94	06-Sep-94	07-Sep-94	08-Sep-94	09-Sep-94	10-Sep-94	11-Sep-94	12-Sep-94	13-Sep-94	14-Sep-94	15-Sep-94
SAMPLING LOCATION S1														
Methylene chloride	2,500U	NA	10,000U	636	618	50,000U	100,000U	100,000U	NA	50,000U	50,000U	50,000U	10,000U	10,000U
Trichloroethylene	2,500U	NA	5,000U	852	905	50,000U	50,000U	100,000U	NA	50,000U	50,000U	50,000U	10,000U	10,000U
Benzene	2,500U	NA	5,000U	282J	279J	50,000U	50,000U	100,000U	NA	50,000U	50,000U	50,000U	10,000U	10,000U
Toluene	2,500U	NA	5,000U	500U	105J	50,000U	50,000U	100,000U	NA	50,000U	50,000U	50,000U	10,000U	10,000U
SAMPLING LOCATION S2														
Methylene chloride	4.71J	NA	NA	25U	NA	14.1	NA	8.87	NA	NA	32.0J	NA	5.0U	NA
Acetone	218	NA	NA	591	NA	26.3J	NA	100U	NA	NA	1,000J	NA	100U	NA
Trichloroethylene	5.0U	NA	NA	25U	NA	3.48J	NA	2.20J	NA	NA	50J	NA	5.0U	NA
Methyl-iso-butyl ketone	50U	NA	NA	250U	NA	9.15J	NA	6.52J	NA	NA	500U	NA	10.2J	NA
Methyl ethyl ketone	26.1J	NA	NA	500U	NA	41.4J	NA	100U	NA	NA	67.2J	NA	100U	NA
Benzene	5.0U	NA	NA	25U	NA	1.85J	NA	5.0U	NA	NA	50U	NA	5.0U	NA
Toluene	5.0U	NA	NA	25U	NA	1.23J	NA	0.922J	NA	NA	50U	NA	5.0U	NA
SAMPLING LOCATION S3														
Methylene chloride	5.40	NA	NA	15.5J	NA	14.2	NA	9.39	NA	NA	23.6J	NA	6.28	NA
Acetone	270	NA	NA	1,070	NA	28.8J	NA	21.5J	NA	NA	1,000U	NA	100U	NA
Trichloroethylene	5.0U	NA	NA	25U	NA	3.37J	NA	2.32J	NA	NA	50U	NA	5.0U	NA
Methyl-iso-butyl ketone	50U	NA	NA	250U	NA	9.88J	NA	9.30J	NA	NA	20.5J	NA	4.58J	NA
Methyl ethyl ketone	39.4J	NA	NA	500U	NA	38.6J	NA	100U	NA	NA	1,000U	NA	100U	NA
Benzene	5.0U	NA	NA	25U	NA	1.73J	NA	5.0U	NA	NA	50U	NA	5.0U	NA
Toluene	5.0U	NA	NA	25U	NA	5.0U	NA	5.0U	NA	NA	50U	NA	5.0U	NA
SAMPLING LOCATION S4														
Methylene chloride	5.50	NA	6.86	8.85	11.6	16.6	7.31	9.61	NA	25.4J	500U	250U	9.73	7.22
Trichloroethylene	5.0U	NA	5.0U	1.75J	5.0U	10U	5.0U	5.0U	NA	50U	500U	250U	2.07J	2.02J
Methyl-iso-butyl ketone	50U	NA	50U	50U	50U	100U	50U	3.45J	NA	500U	5,000U	2,500U	50U	50U
Methyl ethyl ketone	100U	NA	100U	100U	100U	28.2J	100U	100U	NA	1,000U	10,000U	5,000U	100U	100U
Benzene	5.0U	NA	5.0U	5.0U	5.0U	10U	5.0U	5.0U	NA	50U	500U	250U	5.0U	5.0U
Toluene	5.0U	NA	5.0U	5.0U	5.0U	10U	5.0U	1.41J	NA	50U	500U	250U	"5.0U	5.0U
SAMPLING LOCATION S10 - Not Analyzed														

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
S = Sampling port

Table C-4. TCL VOC Concentrations - September (continued)

DATE	16-Sep-94	17-Sep-94	18-Sep-94	19-Sep-94	20-Sep-94	21-Sep-94	22-Sep-94	23-Sep-94	24-Sep-94	25-Sep-94	26-Sep-94	27-Sep-94	28-Sep-94	29-Sep-94	30-Sep-94
							SEPTEMBER								
SAMPLING LOCATION S1															
Methylene chloride	500J	NA	100,000U	100,000U	100,000U	NA	5,000U	100,000U	NA	100,000U	100,000U	100,000U	100,000U	50,000U	
Trichloroethylene	500U	NA	100,000U	100,000U	100,000U	NA	5,000U	100,000U	NA	100,000U	100,000U	100,000U	100,000U	50,000U	
Benzene	500U	NA	100,000U	100,000U	100,000U	NA	5,000U	100,000U	NA	100,000U	100,000U	100,000U	100,000U	50,000U	
Toluene	500U	NA	100,000U	100,000U	100,000U	NA	5,000U	100,000U	NA	100,000U	100,000U	100,000U	100,000U	50,000U	
SAMPLING LOCATION S2															
Methylene chloride	23.8	NA	NA	8.40	NA	NA	NA	3.88J	NA	NA	7.81	NA	3.33J	NA	11.0
Acetone	50U	NA	NA	28.9J	NA	NA	NA	100U	NA	NA	10U	NA	100U	NA	74.0J
Trichloroethylene	5.0U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	1.0U	NA	5.0U	NA	10U
Methyl-iso-butyl ketone	45.0J	NA	NA	50U	NA	NA	NA	10.3J	NA	NA	26.3	NA	23.3J	NA	34.8J
Methyl ethyl ketone	50U	NA	NA	100U	NA	NA	NA	100UJ	NA	NA	10U	NA	100U	NA	5.34J
Benzene	22U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	4.4U	NA	5.0U	NA	10U
Toluene	30U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	6.0U	NA	5.0U	NA	10U
SAMPLING LOCATION S3															
Methylene chloride	50U	NA	NA	9.14	NA	NA	NA	5.47	NA	NA	7.36	NA	5.41	NA	13.1
Acetone	1,000U	NA	NA	76.3J	NA	NA	NA	100U	NA	NA	100U	NA	100U	NA	117J
Trichloroethylene	50U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	5.0U	NA	5.0U	NA	10U
Methyl-iso-butyl ketone	500U	NA	NA	50U	NA	NA	NA	12.5J	NA	NA	13.1J	NA	8.79J	NA	42.2J
Methyl ethyl ketone	1,000U	NA	NA	100U	NA	NA	NA	100UJ	NA	NA	100U	NA	100U	NA	200U
Benzene	50U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	5.0U	NA	5.0U	NA	10U
Toluene	50U	NA	NA	5.0U	NA	NA	NA	5.0U	NA	NA	5.0U	NA	5.0U	NA	1.54J
SAMPLING LOCATION S4															
Methylene chloride	11.2	NA	141	16.0	7.59	NA	"5.0U	5.0U	NA	12.4	7.60	8.66	9.90	9.12	11.8
Trichloroethylene	5.0U	NA	50U	3.66J	5.0U	NA	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	2.65J
Methyl-iso-butyl ketone	50U	NA	63.5J	50U	50U	NA	50U	50U	NA	50U	50U	50U	50U	4.57J	50U
Methyl ethyl ketone	100U	NA	1,000U	100U	100U	NA	100U	100UJ	NA	100U	100U	100U	100U	100U	100U
Benzene	5.0U	NA	50U	0.968J	5.0U	NA	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
Toluene	5.0U	NA	50U	5.0U	5.0U	NA	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	1.38U
SAMPLING LOCATION S10 - Not Analyzed															

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
S = Sampling Port

Table C-5. TCL VOC Concentrations - October

DETECTED VOC COMPOUNDS (µg/L)	OCTOBER													
DATE	01-Oct-94	02-Oct-94	03-Oct-94	04-Oct-94	05-Oct-94	06-Oct-94	07-Oct-94	08-Oct-94	09-Oct-94	10-Oct-94	11-Oct-94	12-Oct-94	13-Oct-94	14-Oct-94
SAMPLING LOCATION S1														
Methyl chloride	NA	15,300	50,000U	50,000U	50,000U	50,000U	50,000U	NA	50,000U	50,000U	50,000U	50,000U	50,000U	50,000U
Methylene chloride	NA	25,000U	25,000U	25,000U	25,000U	25,000U	25,000U	NA	25,000U	25,000U	25,000U	25,000U	25,000U	25,000U
o+p-Xylenes	NA	25,000U	25,000U	25,000U	25,000U	25,000U	25,000U	NA	25,000U	25,000U	14,400J	25,000U	25,000U	25,000U
SAMPLING LOCATION S2														
Methylene chloride	NA	NA	5.34J	NA	"10U	NA	3.07J	NA	NA	7.35	NA	7.23	NA	5.0U
Acetone	NA	NA	200U	NA	137J	NA	29.5J	NA	NA	83.4J	NA	223	NA	482
Trichloroethylene	NA	NA	10U	NA	3.13J	NA	5.0U	NA	NA	1.91J	NA	4.19J	NA	2.70J
Methyl-iso-butyl ketone	NA	NA	24.1J	NA	17.4J	NA	8.36J	NA	NA	50U	NA	6.13J	NA	13.6J
Methyl ethyl ketone	NA	NA	200U	NA	200U	NA	100U	NA	NA	100U	NA	56.6J	NA	82.5J
Toluene	NA	NA	10U	NA	10U	NA	5.0U	NA	NA	5.0U	NA	1.44J	NA	1.93J
Methyl chloride	NA	NA	20U	NA	20U	NA	3.27J	NA	NA	10U	NA	10U	NA	10U
SAMPLING LOCATION S3														
Methylene chloride	NA	NA	6.6J	NA	8.30J	NA	2.21J	NA	NA	6.44	NA	7.17	NA	5.08
Acetone	NA	NA	52.6J	NA	200U	NA	61.2J	NA	NA	99.3J	NA	382	NA	365
Trichloroethylene	NA	NA	10U	NA	10U	NA	5.0U	NA	NA	2.19J	NA	4.33J	NA	3.13J
Methyl-iso-butyl ketone	NA	NA	17.9J	NA	22.3J	NA	11.7J	NA	NA	50U	NA	6.90J	NA	9.64J
Methyl ethyl ketone	NA	NA	200U	NA	200U	NA	2.20J	NA	NA	100U	NA	80.5J	NA	78.8J
Toluene	NA	NA	10U	NA	10U	NA	5.0U	NA	NA	5.0U	NA	1.47J	NA	2.05J
Methyl chloride	NA	NA	20U	NA	2.69J	NA	2.21J	NA	NA	10U	NA	10U	NA	20U
SAMPLING LOCATION S4														
Methylene chloride	NA	2.93J	6.49	9.08	8.56	11.6	3.35J	NA	10.5	6.85	5.0U	7.33	5.14	4.45J
Acetone	NA	100U	101	100U	100U	100U	100U	NA	100U	100U	100U	100U	100U	100U
Trichloroethylene	NA	5.0U	5.0U	3.41J	2.95J	3.98J	5.0U	NA	3.14J	2.23J	5.0U	3.95J	2.97J	3.47J
Methyl-iso-butyl ketone	NA	50U	14.7J	50U	50U	50U	50U	NA	50U	50U	50U	50U	50U	50U
Methyl ethyl ketone	NA	100U	29.8J	100U	100U	100U	100U	NA	100U	100U	100U	100U	100U	100U
Benzene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
Toluene	NA	0.604J	5.0U	5.0U	5.0U	0.744J	5.0U	NA	5.0U	5.0U	1.57J	1.37J	1.01J	2.74J
Chloroform	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	14.0	5.0U	5.0U	5.0U
Ethylbenzene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	2.12J
Styrene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
SAMPLING LOCATION S10														
Methylene Chloride	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1,2,2-Tetrachloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toluene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
S = Sampling Port

Table C-5. TCL VOC Concentrations - October (continued)

DETECTED VOC COMPOUNDS (µg/L)	OCTOBER																
DATE	15-Oct-94	16-Oct-94	17-Oct-94	18-Oct-94	19-Oct-94	20-Oct-94	21-Oct-94	22-Oct-94	23-Oct-94	24-Oct-94	25-Oct-94	26-Oct-94	27-Oct-94	28-Oct-94	29-Oct-94	30-Oct-94	31-Oct-94
SAMPLING LOCATION S1																	
Methyl chloride	NA	50,000U	50,000U	50,000U	100,000U	100,000U	100,000U	NA	100,000U	200,000U	200,000U	100,000U	200,000U	200,000U	NA	200,000U	
Methylene chloride	NA	25,000U	25,000U	25,000U	50,000U	50,000U	50,000U	NA	50,000U	100,000U	100,000U	50,000U	100,000U	100,000U	NA	100,000U	
o+p Xylenes	NA	25,000U	25,000U	25,000U	50,000U	50,000U	50,000U	NA	50,000U	100,000U	100,000U	50,000U	100,000U	100,000U	NA	100,000U	
SAMPLING LOCATION S2									S2								
Methylene chloride	NA	NA	8.11	NA	7.40	NA	6.49	NA	NA	5.10	NA	25U	NA	6.18	NA	NA	5.0U
Acetone	NA	NA	2,680	NA	71.1J	NA	45.2J	NA	NA	55.7J	NA	3,050	NA	304	NA	NA	314
Trichloroethylene	NA	NA	4.20J	NA	3.61J	NA	2.81J	NA	NA	2.50J	NA	25U	NA	2.59J	NA	NA	5.0U
Methyl iso butyl ketone	NA	NA	8.32J	NA	45.7J	NA	45.5J	NA	NA	27.0J	NA	250U	NA	14.4J	NA	NA	50U
Methyl ethyl ketone	NA	NA	349	NA	100U	NA	100U	NA	NA	100U	NA	1,000	NA	49.5J	NA	NA	62.4J
Toluene	NA	NA	5.0U	NA	2.12J	NA	5.0U	NA	NA	5.0U	NA	25U	NA	5.0U	NA	NA	5.0U
Methyl chloride	NA	NA	10U	NA	10U	NA	10U	NA	NA	10U	NA	50U	NA	10U	NA	NA	10U
SAMPLING LOCATION S3																	
Methylene chloride	NA	NA	8.45	NA	7.03	NA	5.77	NA	NA	5.23	NA	25U	NA	6.14	NA	NA	10U
Acetone	NA	NA	1,300	NA	181	NA	140	NA	NA	75.5J	NA	769	NA	256	NA	NA	864
Trichloroethylene	NA	NA	4.68J	NA	2.96J	NA	2.60J	NA	NA	2.73J	NA	25U	NA	2.43J	NA	NA	10U
Methyl-iso-butyl ketone	NA	NA	10.1J	NA	39.2J	NA	53.9	NA	NA	31.8J	NA	250U	NA	10.5J	NA	NA	100U
Methyl ethyl ketone	NA	NA	159	NA	21.0J	NA	100U	NA	NA	100U	NA	500U	NA	37.4J	NA	NA	200U
Toluene	NA	NA	1.89J	NA	1.85J	NA	2.05J	NA	NA	0.918J	NA	25U	NA	5.0U	NA	NA	2.03J
Methyl chloride	NA	NA	10U	NA	10U	NA	10U	NA	NA	10U	NA	50U	NA	10U	NA	NA	20U
SAMPLING LOCATION S4																	
Methylene chloride	NA	8.03	8.01	9.02	7.27	9.06	5.72	NA	4.99J	4.62J	11.4	6.68	6.91	6.16	NA	1.97J	5.0U
Acetone	NA	100U	100U	100U	100U	100U	100U	NA	100U	100U	100U	100U	100U	100U	NA	100U	100U
Trichloroethylene	NA	5.0U	4.52J	4.41J	3.51J	4.21J	2.75J	NA	2.02J	2.88J	6.15	3.30J	3.67J	2.62J	NA	5.0U	5.0U
Methyl-iso-butyl ketone	NA	50U	50U	50U	50U	50U	50U	NA	50U	50U	50U	50U	50U	50U	NA	50U	50U
Methyl ethyl ketone	NA	100U	100U	100U	100U	100U	100U	NA	100U	100U	100U	100U	100U	100U	NA	100U	1.33J
Benzene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	1.30J	5.0U	5.0U	5.0U	NA	5.0U	50U
Toluene	NA	5.0U	2.03J	2.05J	3.11J	2.17J	1.76J	NA	0.770J	5.0U	2.31J	5.0U	1.05J	5.0U	NA	5.0U	1.58J
Chloroform	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U
Ethylbenzene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U
Styrene	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	2.36J	5.0U	5.0U	5.0U	NA	5.0U	5.0U
SAMPLING LOCATION S10																	
Methylene Chloride	NA	NA	NA	NA	NA	7.53	NA	NA	NA	NA	NA	NA	5.0U	5.0U	NA	NA	5.0U
1,1,2,2-Tetrachloroethane	NA	NA	NA	NA	NA	5.0U	NA	NA	NA	NA	NA	NA	1.14J	5.0U	NA	NA	5.0U
Toluene	NA	NA	NA	NA	NA	5.0U	NA	NA	NA	NA	NA	NA	5.0U	5.0U	NA	NA	5.0U

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
S = SamplingPort

Table C-6. TCL VOC Concentrations - November

DETECTED VOC COMPOUNDS (µg/L)	NOVEMBER							08-Nov-94 TIME*					
DATE	01-Nov-94	02-Nov-94	03-Nov-94	04-Nov-94	05-Nov-94	06-Nov-94	07-Nov-94	800	1000	1200	1400	09-Nov-94	10-Nov-94
SAMPLING LOCATION S1 - Not detected													
SAMPLING LOCATION S2													
Methylene chloride	NA	6.46	NA	25U	NA	NA	12.3J	12.0	22.8	47.2	13.6	25U	NA
Acetone	NA	130	NA	1,000	NA	NA	673	946	115	229	678	946	NA
Trichloroethylene	NA	1.40J	NA	25U	NA	NA	13U	4.15J	9.73	19.6	13U	25U	NA
Methyl-iso-butyl ketone	NA	7.67J	NA	250U	NA	NA	130U	50U	50U	10.5J	130U	250U	NA
Methyl ethyl ketone	NA	22.5J	NA	96.9J	NA	NA	250U	43.6J	100U	57.3J	71.5J	73.2J	NA
Benzene	NA	5.0U	NA	25U	NA	NA	13U	5.0U	5.0U	4.52J	13U	25U	NA
Toluene	NA	5.0U	NA	25U	NA	NA	3.93J	5.0U	2.28J	6.09	ND	25U	NA
Ethylbenzene	NA	5.0U	NA	25U	NA	NA	13U	5.0U	5.0U	5.0U	ND	25U	NA
Styrene	NA	5.0U	NA	25U	NA	NA	13U	5.0U	5.0U	3.68J	ND	25U	NA
Chlorobenzene	NA	5.0U	NA	25U	NA	NA	13U	5.0U	5.0U	5.0U	ND	25U	NA
Carbon disulfide	NA	100U	NA	500U	NA	NA	250U	100U	100U	100U	100U	500U	NA
SAMPLING LOCATION S3													
Methylene chloride	NA	4.25J	NA	25U	NA	NA	25U	11.3	25.9	46.9	100U	50U	NA
Acetone	NA	171	NA	1,070	NA	NA	587	489	269	207	2,100	1,450	NA
Trichloroethylene	NA	5.0U	NA	25U	NA	NA	25U	3.88J	11.0	20.1	100U	50U	NA
Methyl-iso-butyl ketone	NA	11.4J	NA	250U	NA	NA	250U	8.16J	100U	100U	1,000U	500U	NA
Methyl ethyl ketone	NA	100U	NA	500U	NA	NA	500U	151	200U	200U	2,000U	1,000U	NA
Toluene	NA	5.0U	NA	25U	NA	NA	4.53J	5.0U	1.89J	6.24J	100U	50U	NA
Benzene	NA	5.0U	NA	25U	NA	NA	25U	5.0U	10U	5.04J	100U	50U	NA
Styrene	NA	5.0U	NA	25U	NA	NA	25U	5.0U	10U	2.08J	100U	50U	NA
Carbon disulfide	NA	100U	NA	500U	NA	NA	500U	100U	200U	200U	2,00U	1,000U	NA
SAMPLING LOCATION S4													
Methylene chloride	4.39J	2.68J	6.27	3.16J	NA	4.63J	12.2	11.3	22.6	46.9	14.9	4.51J	13.4
Acetone	100U	100U	100U	100U	NA	100U	100U	100U	100U	33.2J	100U	100U	100U
Trichloroethylene	1.20J	1.45J	1.76U	5.0U	NA	5.0U	5.24	3.89J	10.3	19.7	3.48J	5.0U	5.02
Methyl ethyl ketone	100U	100U	100U	100U	NA	100U	100U	100U	100U	46.8J	100U	100U	100U
Toluene	5.0U	5.0U	5.0U	5.0U	NA	1.01J	2.93J	2.96J	2.23J	6.61	2.13J	5.0U	5.0U
Benzene	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	4.61J	5.0U	5.0U	5.0U
Ethylbenzene	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
Styrene	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U	9.33	5.0U	5.0U	5.0U
m+p-Xylenes	5.0U	5.0U	5.0U	100U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
SAMPLING LOCATION S10													
Acetone	NA	100U	NA	100U	NA	NA	100U	100U	100U	100U	100U	100U	NA
Methyl ethyl ketone	NA	100U	NA	100U	NA	NA	100U	100U	100U	100U	100U	100U	NA
Carbon disulfide	NA	100U	NA	100U	NA	NA	100U	100U	100U	100U	100U	100U	NA

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
* = Shock Load
S = Sampling Port

Table C-6. TCL VOC Concentrations - November (continued)

DETECTED VOC COMPOUNDS (mg/L)	NOVEMBER												
DATE	11-Nov-94	12-Nov-94	13-Nov-94	14-Nov-94	15-Nov-94	16-Nov-94	17-Nov-94	18-Nov-94	19-Nov-94	20-Nov-94	21-Nov-94	22-Nov-94	23-Nov-94
SAMPLING LOCATION S1 - Not detected													
SAMPLING LOCATION S2													
Methylene chloride	10.9	NA	NA	50U	NA	9.61J	NA	12.6	NA	NA	10U	NA	25U
Acetone	410	NA	NA	2,010	NA	541	NA	762	NA	NA	444	NA	575
Trichloroethylene	10U	NA	NA	50U	NA	13U	NA	4.11J	NA	NA	10U	NA	25U
Methyl-iso-butyl ketone	100U	NA	NA	500U	NA	130U	NA	50U	NA	NA	100U	NA	250U
Methyl ethyl ketone	200U	NA	NA	280J	NA	303	NA	269	NA	NA	200U	NA	107J
Benzene	10U	NA	NA	50U	NA	13U	NA	5.0U	NA	NA	10U	NA	25U
Toluene	10U	NA	NA	50U	NA	13U	NA	2.01	NA	NA	2.11J	NA	25U
Ethylbenzene	10U	NA	NA	50U	NA	13U	NA	5.0U	NA	NA	10U	NA	25U
Styrene	10U	NA	NA	50U	NA	13U	NA	5.0U	NA	NA	10U	NA	25U
Chlorobenzene	10U	NA	NA	50U	NA	13U	NA	5.0U	NA	NA	10U	NA	25U
Carbon disulfide	200U	NA	NA	1,000U	NA	2.19J	NA	3.08J	NA	NA	2.54J	NA	2.91J
SAMPLING LOCATION S3													
Methylene chloride	25U	NA	NA	8.47	NA	11.1	NA	13.0	NA	NA	11.4J	NA	10U
Acetone	771	NA	NA	1,160	NA	150	NA	794	NA	NA	690	NA	322
Trichloroethylene	25U	NA	NA	5.0U	NA	3.18J	NA	5.93J	NA	NA	25U	NA	10U
Methyl-iso-butyl ketone	"250U	NA	NA	50U	NA	20.3J	NA	100U	NA	NA	250U	NA	100U
Methyl ethyl ketone	500U	NA	NA	123	NA	8.91J	NA	312	NA	NA	160J	NA	50.7J
Toluene	25U	NA	NA	5.0U	NA	5.0U	NA	1.99J	NA	NA	25U	NA	10U
Benzene	25U	NA	NA	5.0U	NA	5.0U	NA	10U	NA	NA	25U	NA	10U
Styrene	25U	NA	NA	5.0U	NA	5.0U	NA	10U	NA	NA	25U	NA	10U
Carbon disulfide	500U	NA	NA	1.53J	NA	1.95J	NA	3.35J	NA	NA	500U	NA	3.16J
SAMPLING LOCATION S4													
Methylene chloride	11.6	NA	10.3	7.63	12.7	12.2	11.1	13.6	NA	12.1	8.33	60.9	5.0U
Acetone	100U	NA	100U	100U	100U	100U	100U	100U	NA	100U	100U	100U	100U
Trichloroethylene	3.64J	NA	3.26J	5.0U	4.11J	3.43J	3.81J	4.79J	NA	4.49J	2.57J	22.9	5.0U
Methyl ethyl ketone	100U	NA	100U	100U	100U	100U	100U	100U	NA	9.58J	4.14J	100U	29.1J
Toluene	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	1.54J	NA	1.44J	1.74J	7.67	5.0U
Benzene	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	7.54	5.0U
Ethylbenzene	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	2.19J	5.0U
Styrene	5.0U	NA	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	NA	5.0U	5.0U	16.4	5.0U
m+p- Xylenes	5.0U	NA	5.0U	5.0U	1.58J	5.0U	5.0U	5.0U	NA	5.0U	5.0U	5.0U	5.0U
SAMPLING LOCATION S10													
Acetone	100U	NA	NA	100U	NA	NA	NA	100U	NA	NA	100U	ND	29.1J
Methyl ethyl ketone	100U	NA	NA	100U	NA	NA	NA	100U	NA	NA	100U	ND	8.46J
Carbon disulfide	100U	NA	NA	100U	NA	NA	NA	100U	NA	NA	100U	ND	0.029

J = Estimated Concentration (also used when compound is detected below quantitation limit)
U = Not Detected (detection limit reported)
S = Sampling Port

Table C-7. COD Analytical Results - September (mg/kg)

DATE	S1	S2	S3	S4	S10
02-Sep-94	4,280	453	257	84	NA
03-Sep-94	NA	NA	NA	NA	NA
04-Sep-94	NA	NA	NA	NA	NA
05-Sep-94	2,750	95	367	153	NA
06-Sep-94	3,820	75	3,500	142	NA
07-Sep-94	2,990	974	1,040	550	NA
08-Sep-94	3,970	NA	NA	277	NA
09-Sep-94	4,310	812	852	852	NA
10-Sep-94	NA	NA	NA	NA	NA
11-Sep-94	3,740	NA	NA	809	NA
12-Sep-94	4,140	2,360	2,360	863	NA
13-Sep-94	4,140	NA	NA	600	NA
14-Sep-94	3,680	2,130	1,810	501	NA
15-Sep-94	5,380	NA	NA	256	NA
16-Sep-94	1,490	4,010	10,000	321	NA
17-Sep-94	NA	NA	NA	NA	NA
18-Sep-94	6,510	NA	NA	120	NA
19-Sep-94	6,890	9,243	746	390	NA
20-Sep-94	NA	NA	NA	NA	NA
21-Sep-94	NA	NA	NA	NA	NA
22-Sep-94	6,680	NA	NA	909	NA
23-Sep-94	7,380	6,310	5,620	1,160	NA
24-Sep-94	NA	NA	NA	NA	NA
25-Sep-94	6,920	NA	NA	437	NA
26-Sep-94	6,760	14,100	13,400	444	NA
27-Sep-94	6,990	NA	NA	922	NA
28-Sep-94	13,600	14,200	14,000	460	NA
29-Sep-94	4,150	NA	NA	470	NA
30-Sep-94	7,450	8,892	14,388	888	NA

S = Sampling Port

Table C-8. COD Analytical Results - October (mg/kg)

DATE	S1	S2	S3	S4	S10
02-Oct-94	5,183	NA	NA	528	NA
03-Oct-94	4,880	9,752	11,910	14	NA
04-Oct-94	4,518	NA	NA	843	NA
05-Oct-94	4,497	11,140	11,850	431	NA
06-Oct-94	4,040	NA	NA	771	NA
07-Oct-94	2,932	13,740	14,930	562	NA
08-Oct-94	NA	NA	NA	NA	NA
09-Oct-94	5,380	NA	NA	10	NA
10-Oct-94	4,700	7,250	8,970	362	NA
11-Oct-94	4,910	NA	NA	532	NA
12-Oct-94	5,170	15,100	12,400	545	NA
13-Oct-94	4,960	NA	NA	447	NA
14-Oct-94	5,450	18,800	19,400	418	NA
15-Oct-94	NA	NA	NA	NA	NA
16-Oct-94	4,500	NA	NA	483	NA
17-Oct-94	5,410	2,910	2,990	469	NA
18-Oct-94	4,600	NA	NA	662	NA
19-Oct-94	4,830	19,200	16,500	782	NA
20-Oct-94	NA	NA	NA	NA	NA
21-Oct-94	4,450	11,300	20,700	566	NA
22-Oct-94	NA	NA	NA	NA	NA
23-Oct-94	2,430	NA	NA	1,190	NA
24-Oct-94	6,060	19,700	20,900	1,880	NA
25-Oct-94	6,340	NA	NA	1,620	NA
26-Oct-94	6,140	20,400	19,200	1,550	NA
27-Oct-94	5,820	NA	NA	1,250	1,090
28-Oct-94	5,910	19,400	18,100	481	NA
29-Oct-94	NA	NA	NA	NA	NA
30-Oct-94	5,060	NA	NA	351	NA
31-Oct-94	5,200	9,530	18,800	516	64

S = Sampling Port

Table C-9. COD Analytical Results - November (mg/kg)

DATE	TIME*	S1	S2	S3	S4	S10
01-Nov-94		5,230	NA	NA	513	NA
02-Nov-94		5,980	19,400	19,800	408	441
03-Nov-94		5,300	NA	NA	405	NA
04-Nov-94		6,140	18,200	24,100	405	78
05-Nov-94		NA	NA	NA	NA	NA
06-Nov-94		5,770	NA	NA	1,290	NA
07-Nov-94		6,400	21,500	11,800	1,320	75
08-Nov-94	800	5,910	25,700	2,770	1,170	100
08-Nov-94	1000	16,300	17,900	27,200	1,080	138
08-Nov-94	1200	19,600	20,000	21,400	1,180	121
08-Nov-94	1400	18,500	13,300	21,100	1,260	1,040
09-Nov-94		20,600	22,400	12,500	1,520	93
10-Nov-94		20,200	NA	NA	1,450	NA
11-Nov-94		18,100	2,590	13,000	60	56
12-Nov-94		NA	NA	NA	NA	NA
13-Nov-94		17,100	NA	NA	627	NA
14-Nov-94		19,900	2,030	3,690	1,020	177
15-Nov-94		19,200	NA	NA	2,140	NA
16-Nov-94		18,400	18,200	6,540	823	218
17-Nov-94		16,200	NA	NA	355	NA
18-Nov-94		20,700	2,380	2,170	860	283
19-Nov-94		NA	NA	NA	NA	NA
20-Nov-94		21,900	NA	NA	1,220	NA
21-Nov-94		21,400	3,740	4,170	1,010	436
23-Nov-94		21,400	3,740	4,170	1,010	436

* = Shock Load

S = Sampling Port

Table C-10. Air Analytical Results

SAMPLING LOCATIONS	S8 (Inlet Air Stream)	S6 (Air Recirculation Stream)						S7 (Emissions Stream)						S9 (Emission Stream After Carbon Filter)					
VOCs (ppbv)	9/28	9/14	9/28	10/12	10/25	11/8*	11/21	9/14	9/28	10/12	10/25	11/8*	11/21	9/14	9/28	10/12	10/25	11/8*	11/21
Methyl Methacrylate	1400	16000	730	1100	2200	3700	3400	49.0	110	1800	2100	5400	3900	1.1	2.0	15.0	23.0	ND	7.8
Acetone	460	50.0	46.0	22.0	1600	80.0	20U	63.0	51.0	10U	120	50U	20U	13.0	3.0	10U	80.0	50	1.0U
Benzene	2.0U	120	1.8	9.4	28.0	81.0	2.0U	0.2U	0.2U	8.0	2.0U	380	2.0U	0.2U	0.2U	2.0U	2.0U	5.0U	0.2U
2-Butanone (MEK)	5.0	5.0U	0.2U	0.5U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	0.2U
Chloroform	5.0U	10U	0.5U	3.0	5.0U	20U	10U	1.0U	1.0U	5.0U	5.0U	20U	10U	1.0U	1.0U	5.0U	5.0U	20U	0.5U
1,4-Dichlorobenzene	2.0U	2.0U	0.4	0.2U	2.0U	5.0U	2.0U	0.2U	0.2U	2.0U	2.0U	5.0U	2.0U	0.2U	0.2U	2.0U	2.0U	5.0U	0.2U
Dichloromethane	10U	320	4.0	52.0	140	520	20U	2.0U	2.0U	60.0	120	1300	100	2.0U	110	60.0	10U	50U	140
Ethylbenzene	2.0U	13.0	0.2U	0.5U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	0.2U
1,1,2,2-Tetrachloroethane	1.0U	31.0	0.1U	0.2U	1.0U	5.0U	2.0U	0.2U	0.2U	1.0U	1.0U	5.0U	2.0U	0.2U	0.2U	1.0U	1.0U	5.0U	0.1U
Tetrachloroethene (PCE)	1.0U	2.0U	0.1U	0.2U	1.0U	140	2.0U	0.2U	0.2U	1.0U	1.0U	5.0U	2.0U	0.2U	0.2U	1.0U	1.0U	5.0U	0.1U
Toluene	2.0U	66.0	2.3	12.0	34.0	130	5.0U	0.5U	0.5	14.0	25.0	480	5.0U	0.5U	1.4	2.0U	2.0U	10U	0.2U
Trichloroethene (TCE)	1.0U	280	9.1	48.0	160	520	2.0U	0.2U	0.2U	86.0	180	1700	2.0U	0.2U	3.0	1.0U	28.0	5.0U	0.1U
Trichlorofluoromethane (F-11)	3.0	23.0	0.2U	0.5U	2.0U	5.0U	5.0U	5.0	0.5U	2.0U	2.0U	5.0U	5.0U	20	0.5U	2.0U	2.0U	5.0U	0.2U
Trichlorotrifluoroethane (F-113)	2.0U	16.0	0.4	0.5U	2.0U	10U	5.0U	1.3	0.5U	2.0U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	0.2U
Xylenes	2.0U	5.0U	0.3	0.5U	2.0U	300	5.0U	0.5U	0.5U	2.0U	2.0U	10U	5.0U	0.5U	0.5U	2.0U	2.0U	10U	0.2U
FIXED GASES/METHANE	**9/28**	**9/14**	**9/28**	**10/12**	**10/25**	**11/8**	**11/21**	**9/14**	**9/28**	**10/12**	**10/25**	**11/8**	**11/21**	**9/14**	**9/28**	**10/12**	**10/25**	**11/8**	**11/21**
Carbon Dioxide	0.1U	1.6	0.2	0.5	1.3	1.2	0.1U	0.1U	0.1U	0.8	1.3	1.0	0.1U	0.1U	1.3	0.5	1.3	1.2	0.1U
Oxygen	22.0	21.0	22.0	21.0	20.0	21.0	22.0	22.0	22.0	21.0	20.0	21.0	22.0	22.0	21.0	21	20.0	21.0	22.0
Nitrogen	78.0	77.0	78.0	78.0	79.0	78.0	78.0	78.0	78.0	78.0	79.0	78.0	78.0	78.0	78.0	78	79.0	78.0	78.0
Methane	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U	0.005U
Carbon Monoxide	0.1U	0.1U	01U	0.1U	0.1U	0.005U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U	0.1U

Notes:

* - Shock Load
U - Not detected (value reported is detection limit)

Table C-11. Nutrients

	Ammonia as Nitrogen (mg/L)						Nitrate/Nitrite (mg/L)						Phosphate (mg/L)					
DATE	**S1**	**S2**	**S3**	**S4**	**S5**	**S10**	**S1**	**S2**	**S3**	**S4**	**S5**	**S10**	**S1**	**S2**	**S3**	**S4**	**S5**	**S10**
14-Sep-94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
05-Oct-94	0.11	14	14	0.11	49	NA	0.75	0.4	1.1	0.1	3.9	NA	<0.04	83	96	0.14	1300	NA
19-Oct-94	0.14	0.9	3.7	0.28	11	NA	0.41	0.4	0.14	<0.05	1.2	NA	0.05	120	150	<0.04	1200	NA
02-Nov-94	0.1	29	30	0.78	65	0.59	0.45	0.06	0.64	<0.05	1.5	<0.05	0.19	26	210	1.1	1100	0.94
09-Nov-94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16-Nov-94	0.18	84	93	0.2	0.06	710	0.29	0.47	3.6	<0.05	<0.05	1.6	0.07	170	170	1.3	2	540
23-Nov-94	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

NA - Not Analyzed

< - Corresponding value represents method detection limit; indicates that sample was below detection limit.

Table C-12. Metals Concentrations

ANALYTE									800	1000	TIME* 1200	1400	
(ug/L)	02-Sep-94	16-Sep-94	30-Sep-94	14-Oct-94	20-Oct-94	27-Oct-94	28-Oct-94	07-Nov-94	08-Nov-94	08-Nov-94	08-Nov-94	08-Nov-94	09-Nov-94
SAMPLING LOCATION S1													
Aluminum	220	260	290	330J	NA	NA	270	NA	340	920	1,100	900	740
Arsenic	100U	100U	100U	100UJ	NA	NA	100U	NA	100U	100U	100U	100U	100U
Cadmium	40	74	67	66.00	NA	NA	64	NA	44	110	130	150	160
Chromium	7.8J	6.6J	5.7J	3.5J	NA	NA	4.1J	NA	3.7J	11	16	16	13
Copper	10U	14	8.5J	8.5J	NA	NA	10U	NA	4.3J	4.6J	5.0J	3.1J	2.8J
Iron	9,800	17,100	15,400	21,500	NA	NA	18,600	NA	11,600	29,700	36,500	32,700	34,000
Lead	140	260	220	200	NA	NA	180	NA	110	260	300	330	330
Manganese	84	150	130	140	NA	NA	140	NA	98	230	270	290	290
Mercury	0.20U	0.13J	0.11J	0.13J	NA	NA	0.055J	NA	0.40U	2.0U	2.0U	2.0U	0.14J
Nickel	10J	19J	22	19J	NA	NA	14J	NA	10J	22	27	31	29
Zinc	2,780	4,060	3,070	2,680	NA	NA	1,400	NA	810	1,300	1,400	1,600	2,020
SAMPLING LOCATION S2													
Aluminum	13,300	16,400	20,100	15,600	NA	NA	17,800	19.80	15,300	2,400	15,800	11,500	22,300
Arsenic	100U	100U	100U	100U	NA	NA	100U	0.14	100U	100U	100U	100U	24J
Cadmium	100	410	1,130	1,400	NA	NA	2,070	2.00	1,820	1,930	1,880	1,640	2,260
Chromium	44	250	420	260	NA	NA	150	0.40	130	89	170	100	400
Copper	920	1,130	1,370	1,090	NA	NA	1,050	1.10	790	630	850	630	1,150
Iron	23,400	160,000	363,000	420,000	NA	NA	406,000	586	358,000	225,000	342,000	244,000	623,000
Lead	520	1,800	4,300	3,900	NA	NA	7,300	6.88	4,530	3,000	4,730	3,400	7,690
Manganese	350	988	2,100	2,570	NA	NA	3,430	3.23	3,030	31,200	3,210	2,830	3,650
Mercury	0.14J	3.7	1.1	0.47	NA	NA	1.3J	NA	1.7J	2.2	1.3J	0.93J	0.047J
Sodium							NA						
Nickel	89	230	390	410	NA	NA	398,000	0.53	430	440	470	410	610
Zinc	8,410	26,600	55,800	71,300	NA	NA	86.70	79.60	77,900	83,700	76,900	74,200	95,800
SAMPLING LOCATION S3													
Aluminum	14,500	16,800	18,900	46J	NA	NA	16,500	NA	15,300	19,100	10,000	12,100	24,400
Arsenic	100U	100U	100U	100U	NA	NA	100U	NA	100U	100U	100U	100U	100U
Cadmium	110	423	991	1.5J	NA	NA	1,910	NA	2,000	2,140	1,790	1,660	2,410
Chromium	47	250	380	5.5J	NA	NA	130	NA	120	280	50	81	470
Copper	990.00	1,150	1,300	10U	NA	NA	1,000	NA	800	990	390	630	1,280
Iron	27,200	160,000	296,000	170	NA	NA	357,000	NA	296,000	499,000	142,000	213,000	717,000
Lead	580	1,900	4,100	45U	NA	NA	6,640	NA	4,790	5,740	2,000	3,600	8,400
Manganese	380	1,020	2,050	43	NA	NA	3,240	NA	3,430	3,630	3,160	2,890	3,860
Mercury	0.20U	3.6	1.6	0.15J	NA	NA	2.4	NA	0.93J	0.75J	1.6J	2.2	0.86
Nickel	93	230	380	12J	NA	NA	460	NA	490	550	450	420	660
Zinc	8,920	27,400	49,000	270	NA	NA	84,500	NA	78,000	93,400	76,500	66,100	101,000

Notes:
* - Shock Load ND - Not Detected
J - Not Detected; Corresponding Value Estimated.
U - Not Detected; Corresponding Value Represents the Detection Limit.

Table C-12. Metals Concentrations (continued)

ANALYTE (ug/L)	02-Sep-94	16-Sep-94	30-Sep-94	14-Oct-94	20-Oct-94	27-Oct-94	28-Oct-94	07-Nov-94	TIME* 800 08-Nov-94	1000 08-Nov-94	1200 08-Nov-94	1400 08-Nov-94	09-Nov-94
SAMPLING LOCATION S4													
Aluminum	160	120	86	12.80	NA	NA	130	NA	84	76J	94J	140	160
Arsenic	100U	100U	100U	100U	NA	NA	100U	NA	100U	100U	100U	100U	100U
Cadmium	1.7J	2.9J	1.3J	1.51	NA	NA	4.0U	NA	4.0U	1.2J	1.1J	1.6J	4.0U
Chromium	2.4J	5.6J	10U	0.08	NA	NA	3.4B	NA	2.1J	10U	3.9J	2.9J	10U
Copper	4.5J	9.8J	10U	0.90	NA	NA	10U	NA	10U	4.0J	10U	10U	10U
Iron	40J	64J	200	218	NA	NA	130	NA	140	220	160	170	63J
Lead	45U	9.4J	45U	3.60	NA	NA	16B	NA	13J	45U	45U	45U	45U
Manganese	7.9	21	21	2.60	NA	NA	59	NA	35	43	60	40	50
Mercury	0.075J	0.16J	0.20U	3.3	NA	NA	0.20U	NA	0.20U	0.20U	0.20U	0.20U	0.045J
Nickel	20U	36	8.8J	0.04	NA	NA	5.7B	NA	4.3J	4.6J	6.0J	4.3J	20U
Zinc	71	150	240	70	NA	NA	140	NA	100	140	160	110	86
SAMPLING LOCATION S10													
Aluminum	NA	NA	NA	NA	0.07	0.14	88B	NA	74	80J	120	98J	71J
Arsenic	NA	NA	NA	NA	ND	ND	22B	NA	100U	100U	100U	24J	100U
Cadmium	NA	NA	NA	NA	ND	ND	4.0U	NA	4.0U	0.80J	4.0U	4.0U	4.0U
Chromium	NA	NA	NA	NA	ND	ND	10U	NA	10U	10U	5.3J	10U	10U
Copper	NA	NA	NA	NA	0.01	ND	10U	NA	9.7J	2.0J	10U	10U	10U
Iron	NA	NA	NA	NA	0.20	0.04	59B	NA	35J	30J	46J	30J	120
Lead	NA	NA	NA	NA	ND	ND	45U	NA	45U	13J	9.1J	45U	45U
Manganese	NA	NA	NA	NA	0.01	0.01	6.2	NA	6.1	14	18	27	9.1
Mercury	NA	NA	NA	NA	ND	ND	0.042B	NA	0.40U	0.20U	0.40U	0.20U	0.052J
Nickel	NA	NA	NA	NA	0.01	ND	20U	NA	20U	20U	5.1J	20U	20U
Zinc	NA	NA	NA	NA	0.12	0.01	51	NA	50	32	38	37	37

Notes:

* - Shock Load ND - Not Detected
J - Not Detected; Corresponding Value Estimated.
U - Not Detected; Corresponding Value Represents the Detection Limit.

Table C-13. TSS and VSS

DATE	Total Suspended Solids (mg/L) S1	S4	S10	Volatile Suspended Solids (mg/L) S1	S4	S10
02-Sep-94	12	1	NA	12	1	NA
02-Sep-94	14			14		
05-Sep-94	9	1	NA	9	1	NA
07-Sep-94	7	1	NA	7	1	NA
09-Sep-94	7	1	NA	6	1	NA
12-Sep-94	19	1	NA	16	1	NA
14-Sep-94	6	1	NA	5	1	NA
16-Sep-94	10	1	NA	9	1	NA
18-Sep-94	9	1	NA	7	1	NA
23-Sep-94	7	1	NA	7	1	NA
23-Sep-94	NA	1	NA	NA	1	NA
26-Sep-94	10	1	NA	9	1	NA
28-Sep-94	5	1	NA	4	1	NA
30-Sep-94	3	1	NA	3	1	NA
01-Oct-94	3	2	NA	3	2	NA
05-Oct-94	3	1	NA	3	1	NA
07-Oct-94	5	1	NA	5	1	NA
10-Oct-94	4	1	NA	4	1	NA
12-Oct-94	16	1	NA	10	1	NA
14-Oct-94	36	1	NA	22	1	NA
16-Oct-94	17	1	NA	9	1	NA
19-Oct-94	10	1	NA	6	1	NA
21-Oct-94	8	1	NA	5	1	NA
24-Oct-94	15	1	NA	10	1	NA
26-Oct-94	14	1	NA	12	1	NA
28-Oct-94	14	0.5	NA	12	0.5	NA
31-Oct-94	11	1	1	9.6	1	1
02-Nov-94	10	1	1	8	1	1
04-Nov-94	13	1	1	9	1	1
07-Nov-94	48	1	1	40	1	1
08-Nov-94	18	2	1	15	1	1
08-Nov-94	100	1	1	72	1	1
08-Nov-94	66	1	1	51	1	1
08-Nov-94	71	1	1	52	1	1
09-Nov-94	46	1	1	38	1	1
11-Nov-94	43	1	1	34	1	1
12-Nov-94	19000	1	1	17000	1	1
16-Nov-94	39	1	1	28	1	1
18-Nov-94	33	1	1	30	1	1
20-Nov-94	30	1	1	27	1	1
23-Nov-94	NA	1	1	NA	1	1
28-Nov-94	NA	NA	9100	NA	NA	6300
28-Nov-94	NA	NA	49000	NA	NA	39000

Notes:

NA - Not Analyzed

Table C-14. TOC (mg/L)

	STREAM		
DATE	**S1**	**S4**	**S10**
02-Sep-94	500	120	NA
16-Sep-94	900	800	NA
30-Sep-94	800	120	NA
14-Oct-94	900	140	NA
28-Oct-94	800	170	26
09-Nov-94	3100	340	140